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MICROWAVE TRANSVERSAL EQUALIZER. OPEN LOOP ADAPTIVE COMPUTER CO--ETC(U)

JUL 81 A LEBER, G KANISCHAK, D WANG, M DAIGLE F30602-80-C-0042

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July 1981



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MICROWAVE TRANSVERSAL EQUALIZER OPEN LOOP ADAPTIVE COMPUTER CONTROL TECHNIQUES

Eaton Corporation

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SUMMARY

This final report on Contract F30602-80-C-0042 summarizes the AIL investigation to determine and demonstrate suitable algorithms and corresponding computer software in order to provide open-loop adaptive control of the Microwave Transversal Equalizer (MTE) previously developed by AIL under Contract F3062-78-C-0352.

The program task objectives have been successfully accomplished by AIL with the application of Fast Fourier Transform (FFT) techniques to provide an algorithm programmed on the RADC HP 2100A computer. This procedure will ultimately be utilized to determine the MTE amplitude and time delay adjustments necessary to equalize the distortion introduced by an arbitrary network in series with the equalizer.

Verification of the developed FFT and associated software program was accomplished at AIL with a DEC-20 computer using artificially generated simulated time sidelobe distortion typical of the expected range of levels. Translation of the algorithm from the DEC-20 computer format to the HP 2100A computer format has been completed, and verification of the software program using RADC I and Q data is underway. Preliminary data suggests that the program translation task has been successfully accomplished by AIL. It is expected that optimal data acquisition techniques and/or preferred computer interface procedures will be defined as a result of related post-delivery activities at RADC.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the technical direction of J. Polniaszek and W. Peterson of RADC, Griffiss Air Force Base, Rome, New York.

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1. INTRODUCTION

The objective of Contract F30602-80-C-0042 is to develop an algorithm, and relevant computer software programming for the RADC HP 2100A computer, to facilitate open-loop control of the MTE in order to minimize time sidelobe distortion. The resultant algorithm using FFT techniques and associated programming has been validated with artificially generated simulated distortion data using the AIL DEC-20 computer and the HP 2100A computer at RADC. A similar post-delivery validation effort will be conducted by RADC personnel using real-time distortion data and the HP 2100A computer.

Section 2.0 will contain a brief discussion of MTE operational fundamentals in order to establish an inter-relationship with the algorithm development program. Section 3.0 will present a detailed treatment of the FFT techniques applied to algorithm development for the MTE. Section 4.0 will discuss the resultant computer program including applicable operating and test procedures. Finally, Section 5.0 will present conclusions and recommendations for a logical continuation of effort required to provide closed-loop operation of the MTE.

2. MTE TECHNICAL DISCUSSION

A discussion of distortion considerations and the fundamentals of the MTE operation are presented in order to provide the technical basis for computer control and adaptive equalization of resultant time sidelobe distortion. A detailed description of the MTE, including operating procedures, is included in Final Report RADC-TR-80-121 of 31 January 1980 titled "Microwave Transversal Equalizer".

2.1 PAIRED ECHO THEORY AND DISTORTION CONSIDERATIONS

Algorithms for determining the settings of attenuation and phase for each loop of a transversal equalizer rely heavily on the paired echo concept. Accordingly, a brief review of this theory is given below stressing its applicability to the present program.

2.1.1 Paired Echo Theory

The paired echo concept and its application to the design of a transversal equalizer (MTE) was described in Ref. 1. It should be noted that this work was supported by RADC. This paper also gives a bibliography of prior work on non-microwave MTE's and the now classic reference on Chirp radar by Klander, et al. The latter emphasized the use of paired echo theory to predict time sidelobe levels in Chirp radars. The essential aspects of the paired echo theory are summarized below.

Ref. 1 - J.J. Taub and G.P. Kurpis, "Microwave Transversal Equalizer", Microwave Journal, 1969.

Signals which can be characterized by a time function of its Fourier transform (amplitude and phase vs frequency functions), are subject to distortion when propagating through a microwave component or a system of microwave components (such as a Chirp radar). This distortion occurs because the system's transfer function possesses neither perfectly constant gain nor perfectly linear phase over the spectrum of the signal.

We typically represent the transfer function in the frequency domain and need to predict its effect on time domain distortion. By using the paired theory we can make relatively quick conversions between the frequency domain and the time domain and vice versa.

The system transfer function, or frequency response, of an arbitrary system can be defined as:

$$H(\omega) = A(\omega) e^{jB(\omega)} \quad (2-1)$$

where A and B are respective gain and phase functions defined in Reference 1.

We must now assume that the signal transmitted through the system has spectral components that are band limited. This is a safe assumption for most systems. For example, in many radar applications the signal's spectrum is confined to the electronic bandwidth of the final power amplifier. Within a band limit of ω_l to ω_h we can rigorously represent the A and B functions as Fourier series:

$$A(\omega) = a_0 \left[1 + \sum_{n=1}^N \frac{a_n}{a_0} \cos (n\omega'e) + \phi_n \right] \quad (2-2)$$

and

$$B(\omega) = b_0 \omega' + \sum_{n=1}^N b_n \sin (n\omega'e + \psi_n) + K \quad (2-3)$$

where:

$$\omega' = \omega - \omega_0$$

$$\omega_0 = \frac{\omega_l + \omega_h}{2}$$

$$e = \frac{2\pi}{\omega_0 - \omega_l}$$

In a distortionless network $A(\omega) = a_0$ and $B(\omega) = b_0 \omega'$. Hence the remaining terms contribute to distortion. This representation leads to the time domain response including distortion and so that for a band limited signal $V_i(\omega)$ and its time function equivalent $V_i(t)$ we obtain

$$\begin{aligned} V_0(t) = & a_0 V_i(T + b_0) + a_0 \sum_{n=1}^N E_{n+} V_i(t + b_0 - ne) \\ & + a_0 \sum_{n=1}^N E_{n-} V_i(t + b_0 + ne) \end{aligned} \quad (2-4)$$

where $V_0(t)$ is the output time function and the constants E_{n+} and E_{n-} represent echo or time sidelobe amplitude levels. These levels are related to the Fourier distortion coefficients in equations (2-2) and (2-3). For the case where ϕ_0 and $\psi_0 = 0$ they reduce to

$$E_{n+} = \frac{1}{2} \left(\frac{a_n}{a_0} + b_n \right) \quad (2-5)$$

$$E_{n-} = \frac{1}{2} \left(\frac{a_n}{a_0} - b_n \right)$$

A typical example of a distorted microwave pulse is given in Figure 2-1. The echoes are clearly displayed. This analysis demonstrates that a frequency domain transfer function can be represented by a Fourier series which enables rapid calculation of the time domain response. Conversely, a measurement of the time domain response which yields sidelobe levels can be used to rapidly calculate the a and b coefficients thereby yielding the frequency domain transfer function. The MTE settings cancel distortion by injecting equal and opposite echoes in cascade with the system.

2.1.2 Use of Paired Echo Theory

Since the MTE design and adjustment procedures are based on cancelling distortion echoes, algorithms can be developed by taking either frequency domain (I and Q data) measurements or time domain responses (time sidelobe levels in dB) and converting them into the necessary MTE loop attenuation and phase settings to produce cancelling echoes. The key point of this discussion is that use of paired echo theory simplifies computation and therefore significantly reduces computer time. Furthermore it provides the flexibility to work with either frequency or time domain data. In this program the actual procedure used was to use I and Q data (frequency domain measurements).

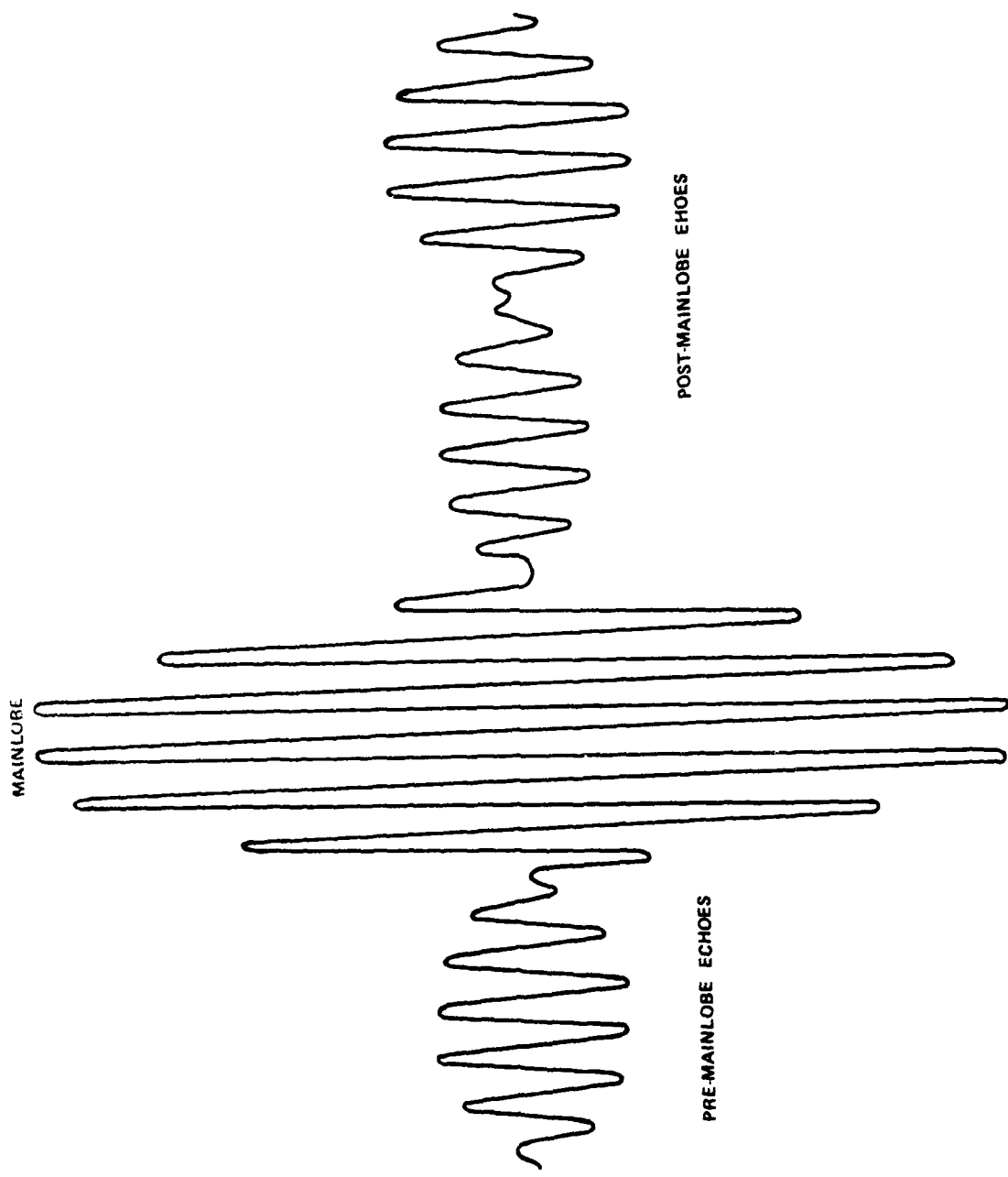


Figure 2-1. Time Sidelobe Distortion.

2.2 MICROWAVE TRANSVERAL EQUALIZER OPERATION

The MTE has been designed by AIL to cancel the parasitic time sidelobes caused by distortion, by generating its own artificial equalizer sidelobes, whose envelopes are properly delayed (or advanced) to coincide in time with the parasitic sidelobes. In addition, the amplitude and phase of each artificial sidelobe can be separately adjusted to produce an equal amplitude phase reversed replica of the corresponding parasitic sidelobe.

Generation of the equalizer echoes is accomplished by tapping off portions of energy from the main signal lobe on the main transmission path, directing these portions through properly adjusted delay lines and reintroducing the delayed signal portions back into the main transmission path with proper amplitudes and polarity. The time domain output response of an ideal MTE is shown in Figure 2-2. It should be noted however that the actual response will consist of a train of echoes with decreasing amplitudes (0.75 dB/tap) due to the insertion loss of the mainline tapped delay elements. A correction for the aforementioned MTE echo transfer characteristics will be necessary in order to achieve the desired tap attenuator setting with adaptive closed loop operation (computer controlled).

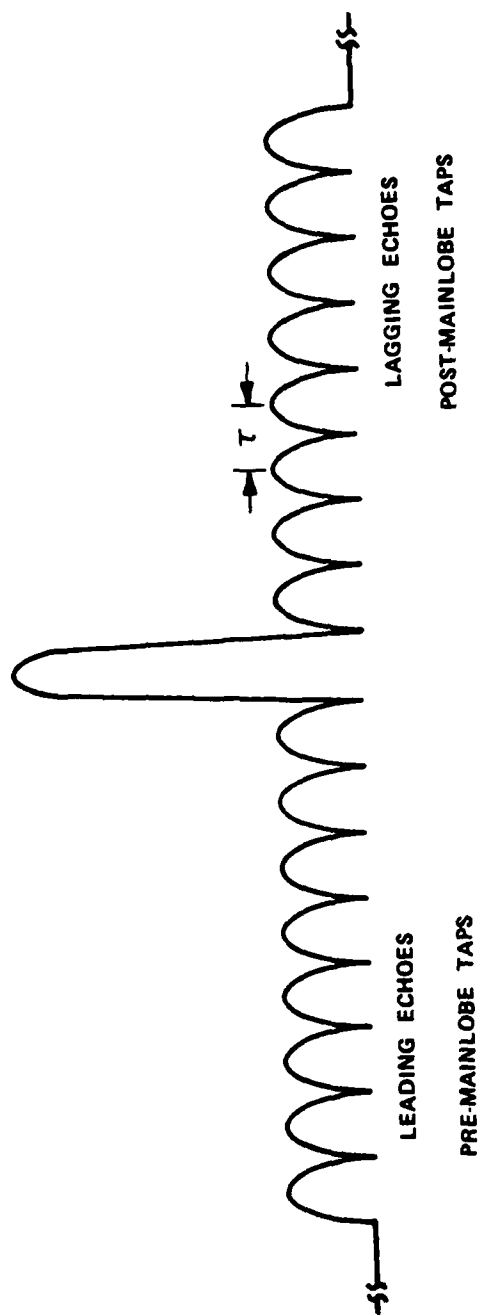


Figure 2-2. Time Domain Output of Microwave Transversal Equalizer.

The MTE consists of four cascade connected microwave integrated circuit mainlines and 32 secondary lines for the purpose of generating a train of 8 pre- and post-mainlobe echoes (16 total). A 3.3 nsec time delay between echoes of each train is provided.* The amplitude level and time delay of the selected 16 of the 32 possible echoes are individually adjusted with the PIN diode variable attenuator (electronically controlled), a line stretcher variable delay (mechanically controlled), included in each secondary line. The remaining 16 echo taps are terminated, however these taps are available for use as required.

It should be noted that the transfer characteristics of each of the 16 variable attenuators, as well as the 16 variable solid state time delay units (when they are developed) are required to properly achieve adaptive MTE control.

*Compatible with a 300 MHz bandwidth.

3. ALGORITHM DEVELOPMENT

An algorithm has been developed using FFT techniques to provide open loop control of the MTE. The technique will be described in terms of the relevant input and output formats, as well as the FFT algorithm.

3.1 INPUT FORMAT

The input to the FFT consists of a set of complex correlations as a function of frequency. These samples can be expressed by

$$H(j\omega_i) \approx I(\omega_i) + jQ(\omega_i) \quad (3-1)$$

where

ω_i is the i^{th} frequency

$I(\omega_i)$ is the in-phase frequency response

$Q(\omega_i)$ is the quad-phase frequency response

For the problem at hand, the following frequencies are considered:

$$\omega_i = 2\pi [f_L + (i-1) \Delta f], \quad i = 1, 2, \dots, 256 \quad (3-2)$$

where

$$f_L = 3.1 \text{ GHz}$$

$$\Delta f = 1.17647 \text{ MHz} \approx 1.18 \text{ MHz}$$

The last frequency is found by setting $i = 256$; that is,

$$f_H = 3.1 + 255 \times 1.18 \times 10^{-3} \approx 3.4 \text{ GHz}$$

As a result, a total of 256 pairs of measurement data are involved for a bandwidth of 300 MHz as shown in the format presented in Table 3-1.

TABLE 3-1. TAPE FORMAT FOR THE FREQUENCY RESPONSE

Word Index	Notation	Frequency
1	$I(j\omega_1)$	3.1 GHz
2	$Q(j\omega_1)$	3.1 GHz
3	$I(j\omega_2)$	$3.1 + \Delta f$
4	$Q(j\omega_2)$	$3.1 + \Delta f$
0	0	0
0	0	0
0	0	0
509	$I(j\omega_{255})$	$3.1 + 254 \Delta f$
510	$Q(j\omega_{255})$	$3.1 + 254 \Delta f$
511	$I(j\omega_{256})$	3.4 GHz
512	$Q(j\omega_{256})$	3.4 GHz

Note:

$$1. \quad \Delta f = \frac{3.4 - 3.1}{255 \times 10^{-3}} \approx 1.18 \text{ MHz}$$

2. Each word is represented by 8 bits in binary 2's complement notation; i.e.:

$$-128 < I, Q < +127$$

The above representation defines the formula transformation required from the input medium to the computer.

The input samples are represented by an 8 bit binary two's complement notation. Thus, a word is defined to be 8 bit with the value of the word ranged from 127 to -128. In floating point notation the value is ranged from

$$\begin{aligned} 127/128 &= 0.992188 \text{ to} \\ -128/128 &= -1 \end{aligned}$$

3.2 OUTPUT FORMAT

The output of the FFT consists of a set of $N_t = 17$ complex MTE tap coefficients which represents a truncated Fourier series representation of the equalizer transfer function. The total number of relative equalizer taps is sixteen with the center tap (number 9) taken as the reference tap.

The output tap coefficient will be presented by decimal representation with the absolute magnitude of the tap less than unity, that is: $-1 \leq C_i < 1$ for $i = 1, 2, \dots, 17$ and phase angle is expressed in degree units.

Further data format transformation will be needed to match the exact setting on the MTE attenuator dial.

3.3 FFT ALGORITHM

Consider again the measured frequency response of a network with a transfer function $H(j\omega_i)$. The measurement can be functionally described by the block diagram shown in Figure 3-1. The input signal to the device can be written as

$$X_i(t) = A_i \cos (\omega_i t + \phi_0) \quad (3-3)$$

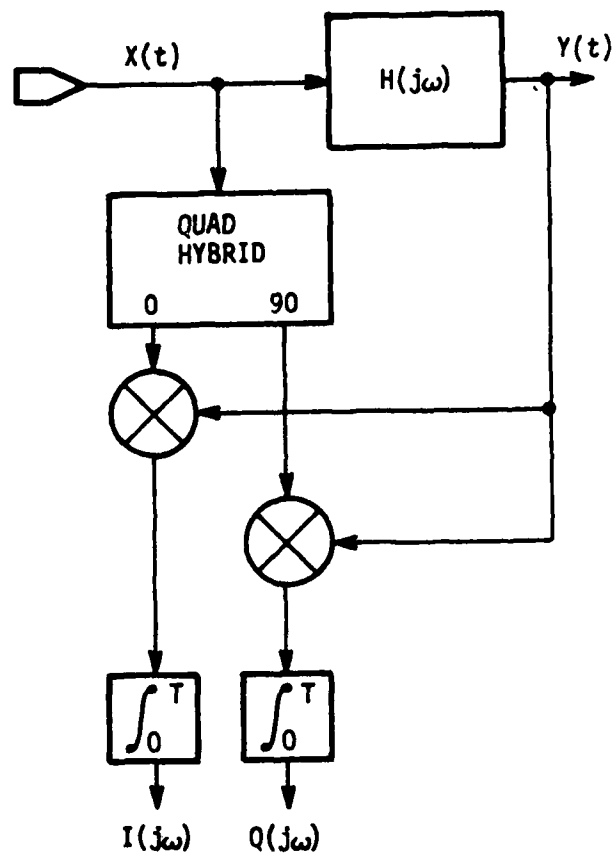


FIGURE 3-1. MEASUREMENT SETUP

where

ω_i is the i^{th} in-band frequency
 θ_0 is the input phase angle
 A is the amplitude of the signal

The response of the network is

$$Y_i(t) = B_i \cos(\omega_i t + \theta_i) \quad (3-4)$$

where

θ_i is the corresponding phase angle for the i^{th} signal
 B_i is the corresponding amplitude for the i^{th} signal

The quadrature hybrid is used to generate the in-phase and the quad-phase components:

$$I(j\omega_i) = \frac{1}{T} \int_0^T A \cdot B_i \cos(\omega_i t + \theta_0) \cos(\omega_i t + \theta_i) dt \quad (3-5)$$

and

$$Q(j\omega_i) = \frac{1}{T} \int_0^T A \cdot B_i \sin(\omega_i t + \theta_0) \cos(\omega_i t + \theta_i) dt \quad (3-6)$$

where T is defined as the correlation time. The correlator output can be reduced to

$$I(j\omega_i) = \frac{AB_i}{2} \cos(\theta_0 - \theta_i) \quad (3-7)$$

$$Q(j\omega_i) = \frac{AB_i}{2} \sin(\theta_0 - \theta_i) \quad (3-8)$$

The gain and phase response as a function of frequency can be expressed by

$$G_i = \sqrt{I_i^2 + Q_i^2} = \frac{A}{2} \cdot B_i \quad (3-9)$$

$$\theta_i = \tan^{-1} \left(\frac{Q_i}{I_i} \right) + \theta_0 \quad (3-10)$$

where the short hand notation is adapted; that is

$$I_i = I(j\omega_i) \text{ and } Q_i = Q(j\omega_i)$$

Since A and θ_0 are not a function of frequency, these measurement data represent the transfer function $H(j\omega_i)$. The impulse response $h(nT)$ can be found by discrete Fourier transform method.

A few assumptions will be made such that the Fourier series approach can be applied:

- (1) Signals passing through the network will be bandlimited to 300 MHz. To provide equalization over this bandwidth requires a corresponding time delay. This defines the delay between taps to be:

$$T = \frac{1}{f_H - f_L} = \frac{1}{300 \times 10^6} = 3.33 \text{ nsec}$$

- (2) Since any digital filter spectrum to be realized will be made periodic of period f_s , then the spectrum can be represented by a Fourier series:

$$H(j\omega) = \sum_{k=-\infty}^{\infty} c_k \exp(jk\omega T) \quad (3-11)$$

where c_k is the k^{th} Fourier coefficient defined by

$$c_k = \frac{1}{\omega_s} \int_{-\frac{\omega_s}{2}}^{\frac{\omega_s}{2}} H(j\omega) \exp(-jk\omega T) d\omega \quad (3-12)$$

Generally, if the gain response is an even function and the phase response is an odd function, that is

$$G(j\omega) = G(-j\omega) \quad (3-13)$$

$$\theta(j\omega) = -\theta(-j\omega) \quad (3-14)$$

then the resultant coefficients will be real. Note that these requirements that $G(j\omega)$ and $\theta(j\omega)$ be even and odd respectively, lead to similar requirements that the in-phase and the quadrature-phase components to be even and odd, respectively. In practice, however, these symmetries cannot be assumed as shown in Figure 3-2. As a result, the coefficients will be complex; that is:

$$c_k = a_k + j b_k, k = 1, 2, \dots, 17 \quad (3-15)$$

where

$$g_k = \frac{1}{\sqrt{a_k^2 + b_k^2}} \quad (3-16)$$

$$\theta_k = \tan^{-1} (b_k/a_k) \quad (3-17)$$

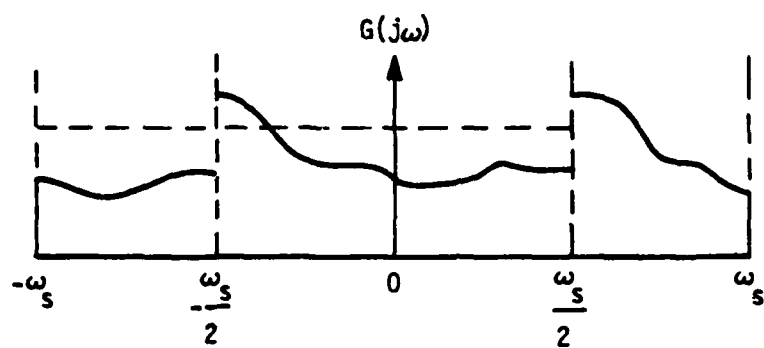
To achieve a set of real equalizer coefficients usually means to double the upper frequency bound of the signal samples (ω_s). When the upper frequency is doubled, the second half of the spectrum is copied from the original bandwidth with the proper polarity attached. Examples to illustrate these properties will be presented in the next section.

3.4 FFT ILLUSTRATIVE EXAMPLES

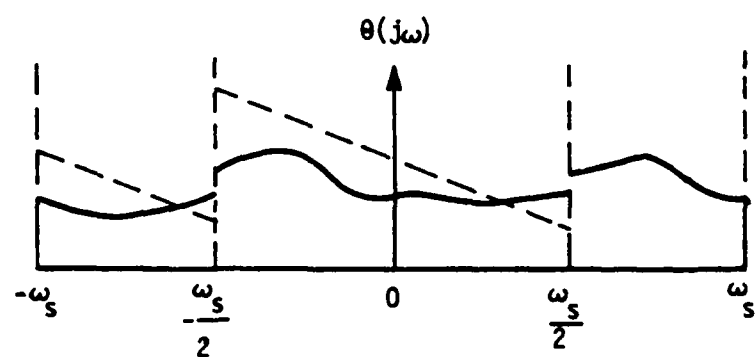
A few examples illustrates the Fourier transform approach to well defined $H(j\omega)$ will be given in this section.

3.4.1 Lowpass Filter

Figure 3-3 shows a specification for a lowpass transfer function with cutoff frequency set at 0.5 rad/sec and the upper frequency bound (ω_s) set at 2 rad/sec. The spectrum between $\omega_s/2$ to

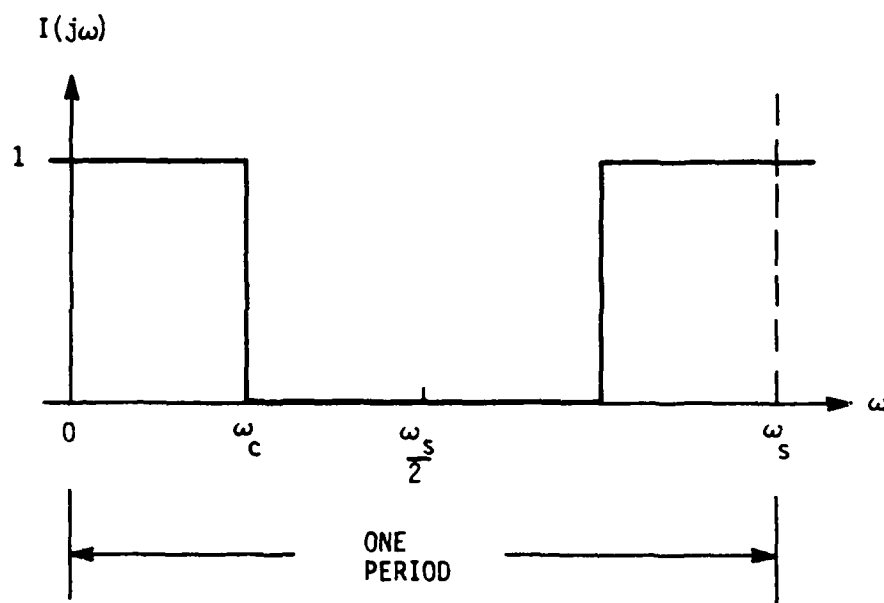


(a) GAIN SPECTRUM



(b) PHASE SPECTRUM

FIGURE 3-2. GAIN AND PHASE RESPONSE (GENERAL CASE - ASYMMETRIC)



$$\omega_s = 2 \text{ RAD/SEC}$$

$$\omega_c = 0.5 \text{ RAD/SEC}$$

$$Q(j\omega) = 0 \text{ FOR ALL } \omega$$

FIGURE 3-3. IDEAL RESPONSE OF A LOWPASS FILTER

ω_s is duplicated to provide an even function for the in-phase response $I(j\omega)$. The quad-phase response is set to zero.

The Fourier coefficients can be readily found to be

$$c_k = \frac{1}{k\pi} \sin(k\pi), \quad k = -N, -N+1, \dots, N \quad (3-18)$$

$k \neq 0 \text{ and } N = 8$

and $C_0 = 0.5$.

For the case $N = 8$, or 17-tap equalizer the response of the network can be plotted as shown in Figure 3-4.

Generally, the performance of such a filter indicates a passband ripple of 0.75 dB and a stopband rejection of approximately -20 dB. Direct truncation of the Fourier series leads to the well-known Gibbs phenomenon. The ripple, in general, cannot be reduced by simply including more taps as displayed by the 25 tap version shown in Figure 3-5.

The reduction of the passband ripple and stopband attenuation is later approached by finding a time-limited function whose Fourier transform best approximates a bandlimited function. This approach leads to the well-known Kaiser window expressed by:

$$\omega(K) = \frac{I_0(\beta \sqrt{1 - (K/N)^2})}{I_0(\beta)} \quad -N < K < N$$

where β is a constant ($1 < \beta < 10$)

I_0 is the modified Bessel function of order zero

N is half the number of taps

The constant β can be determined experimentally. Figure 3-6 shows the same 17 taps frequency response with Kaiser window. The

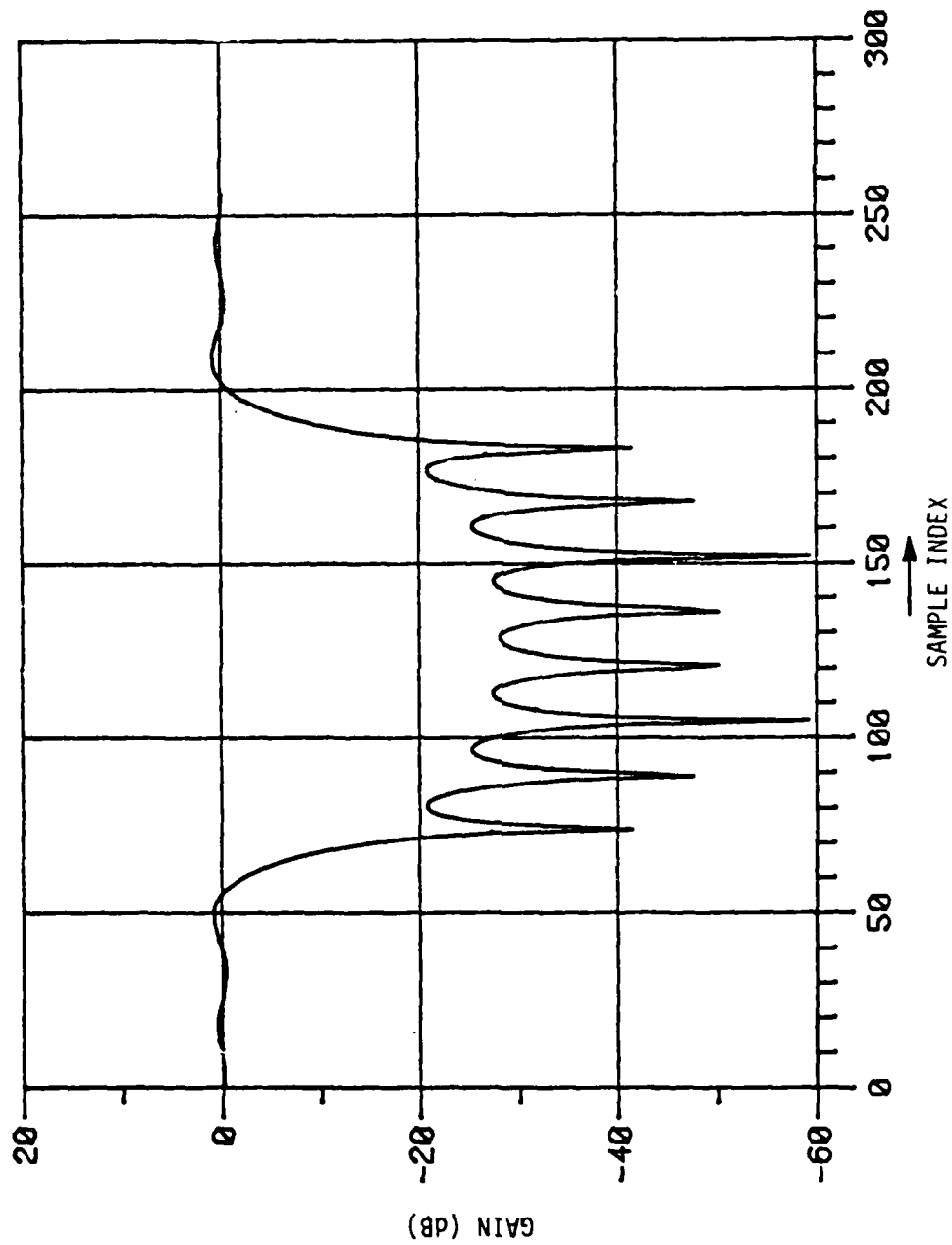


FIGURE 3-4. LOWPASS FILTER RESPONSE (17 Taps) DIRECT TRUNCATION

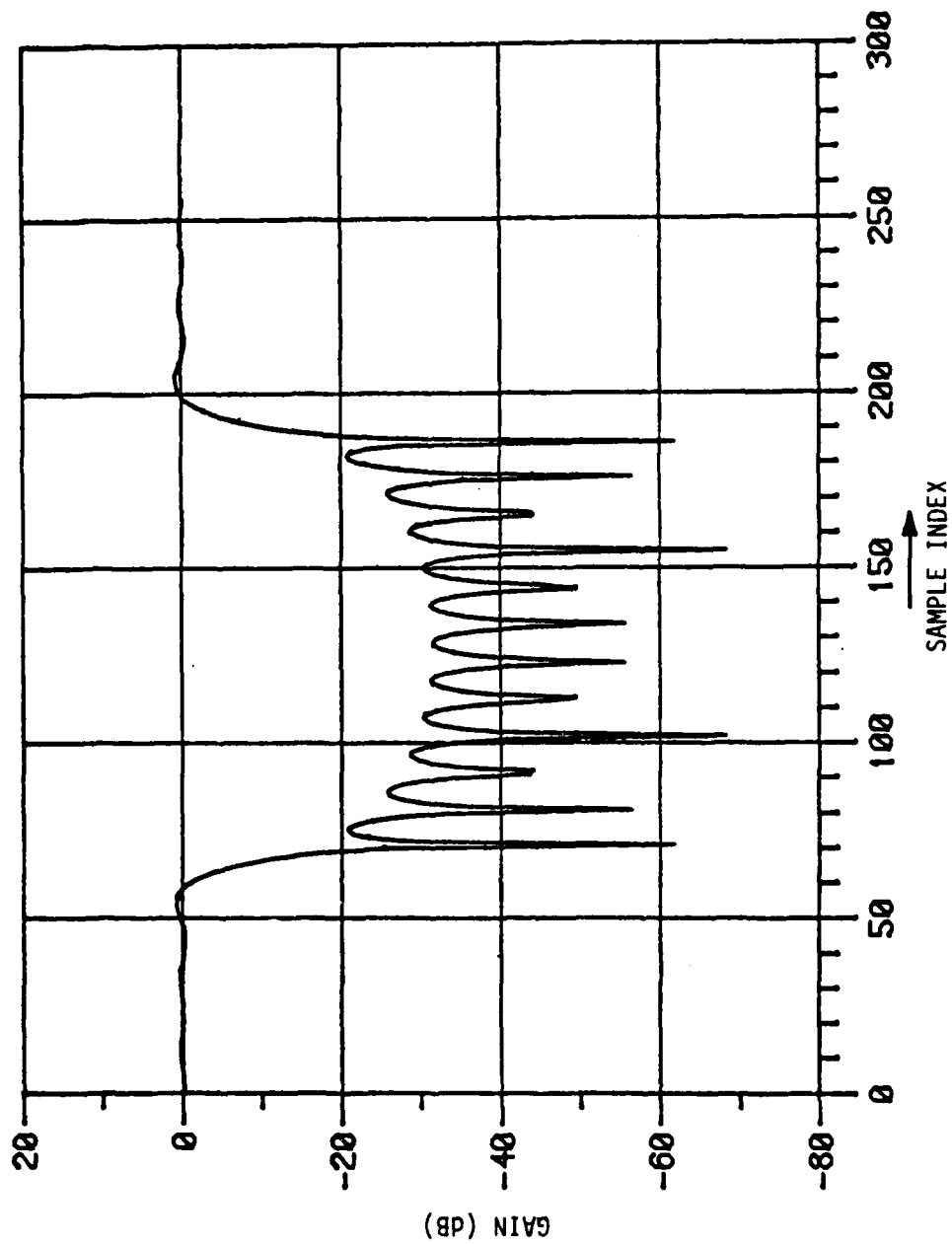


FIGURE 3-5. LOMPAS FILTER RESPONSE (25 Taps) DIRECTED TRUNCATION

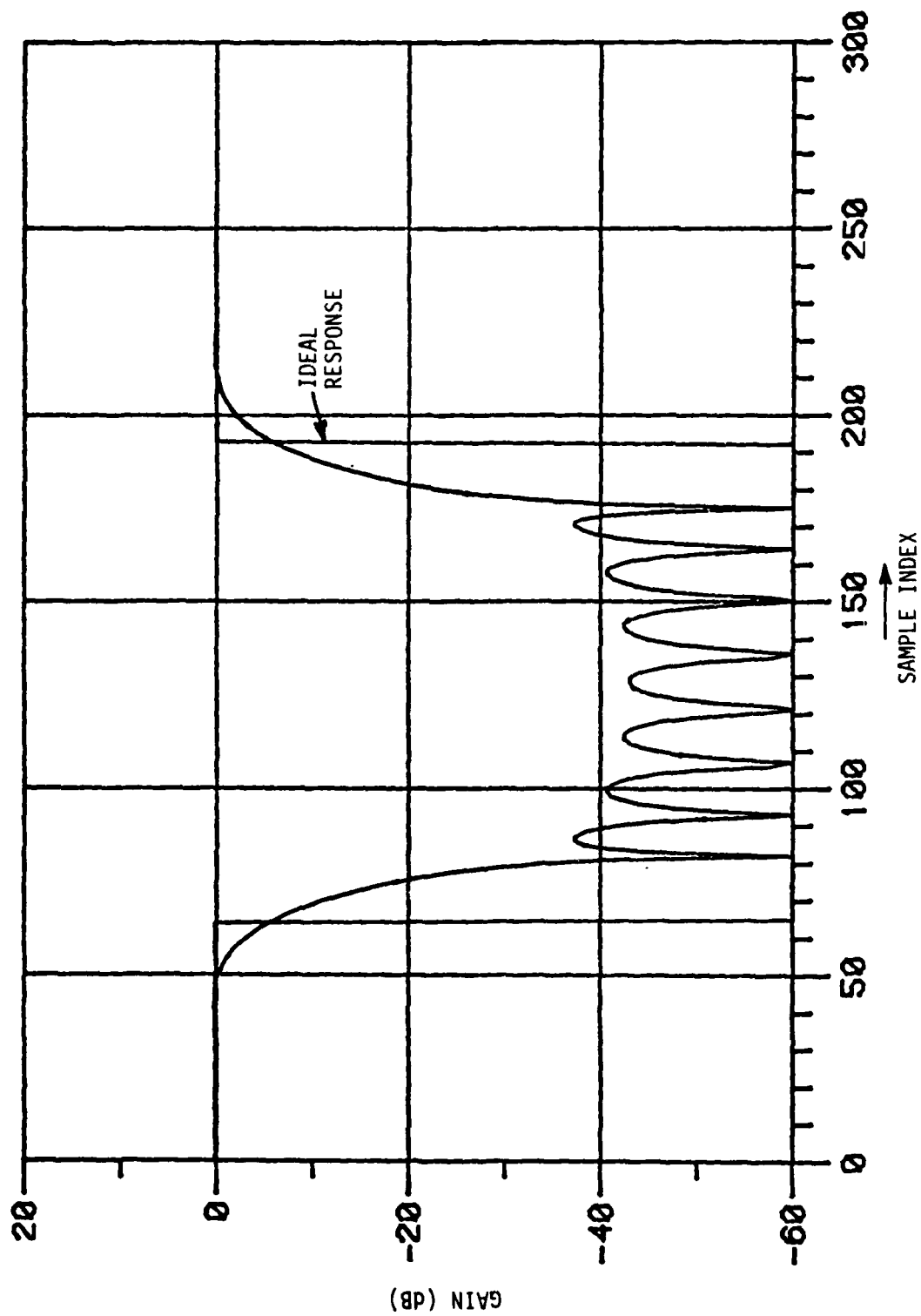


FIGURE 3-6. 17 - Tap LOWPASS FILTER WITH WINDOW

passband ripple is essentially vanished and the stopband rejection is reduced from -20 dB to -38 dB. Note that the windowing operation is a proper scale function applied to the impulse response of the filter. It does not change the hardware configuration of the filter.

3.4.2 A Differentiator

The response of a differentiator can be written by the equation

$$H(j\omega) = j\omega, \text{ for } -\omega_s/2 < \omega < \omega_s/2$$

This is the case that the in-phase response is zero and the quadrature phase is an odd function. As a result, the coefficient (or the impulse response) is real and odd functions; that is,

$$\begin{aligned} c_k &= \frac{2}{\omega_s} \int_0^{\frac{\omega_s}{2}} \omega \sin(k\omega T) d\omega \\ &= \int_0^1 \omega \sin(k\omega T) d\omega \text{ where } T = \frac{2\pi}{\omega_s} = \pi, \omega_s = 2 \\ &= -\frac{\cos(k\pi)}{k\pi}, k = -N, -N+1, -1, 1, \dots, N \\ &\quad k = 0 \end{aligned}$$

where $k = 0, C_0 = 0$.

Figure 3-7 is the response of the filter with 17 taps and Figure 3-8 is the response with Kaiser window. The parameter β for the Kaiser window is set to 3 to reduce the ripple due to direct truncation of the Fourier series at $N = 8$.

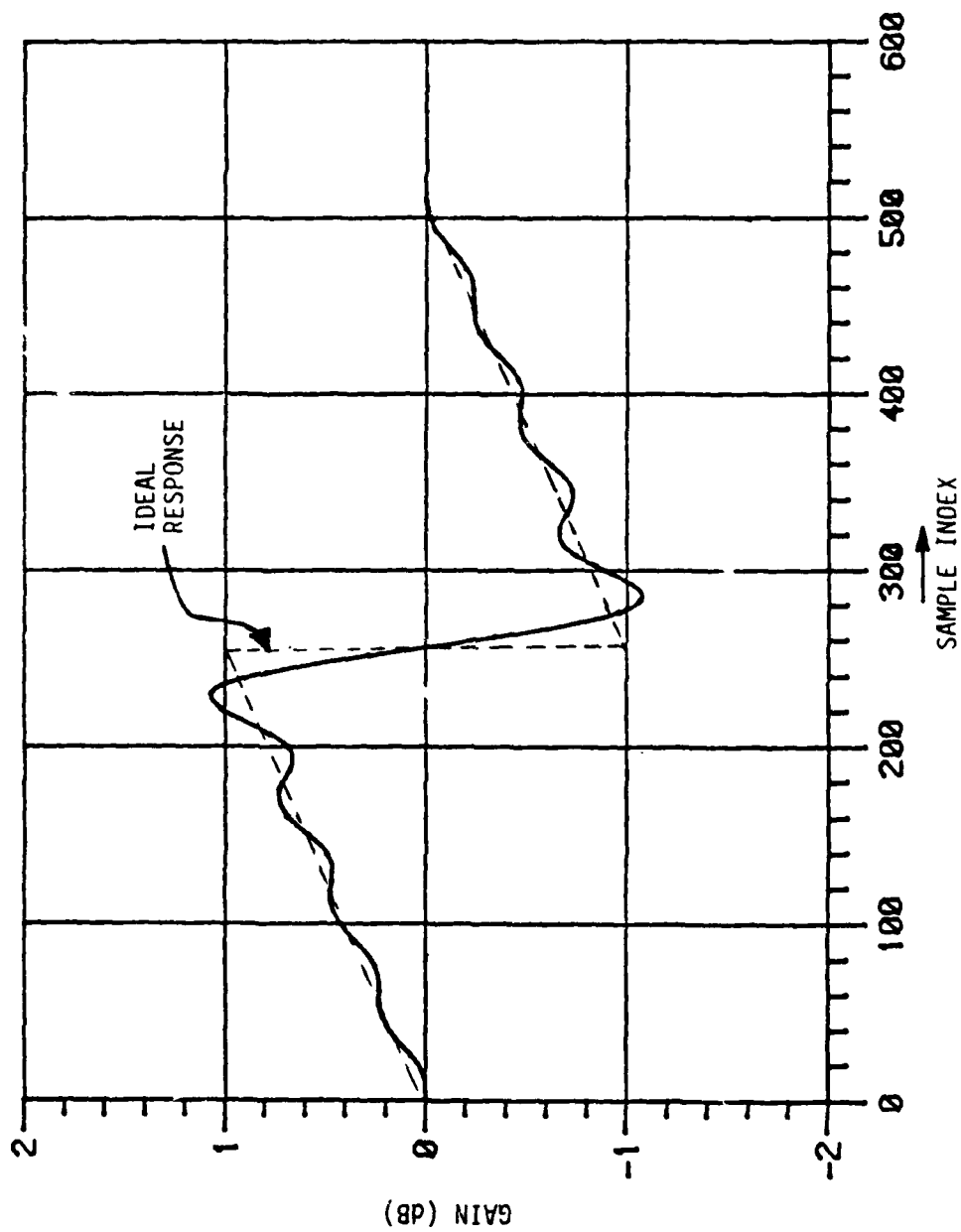


FIGURE 3-7. DIFFERENTIATOR RESPONSE (17 Taps) DIRECT TRUNCATION

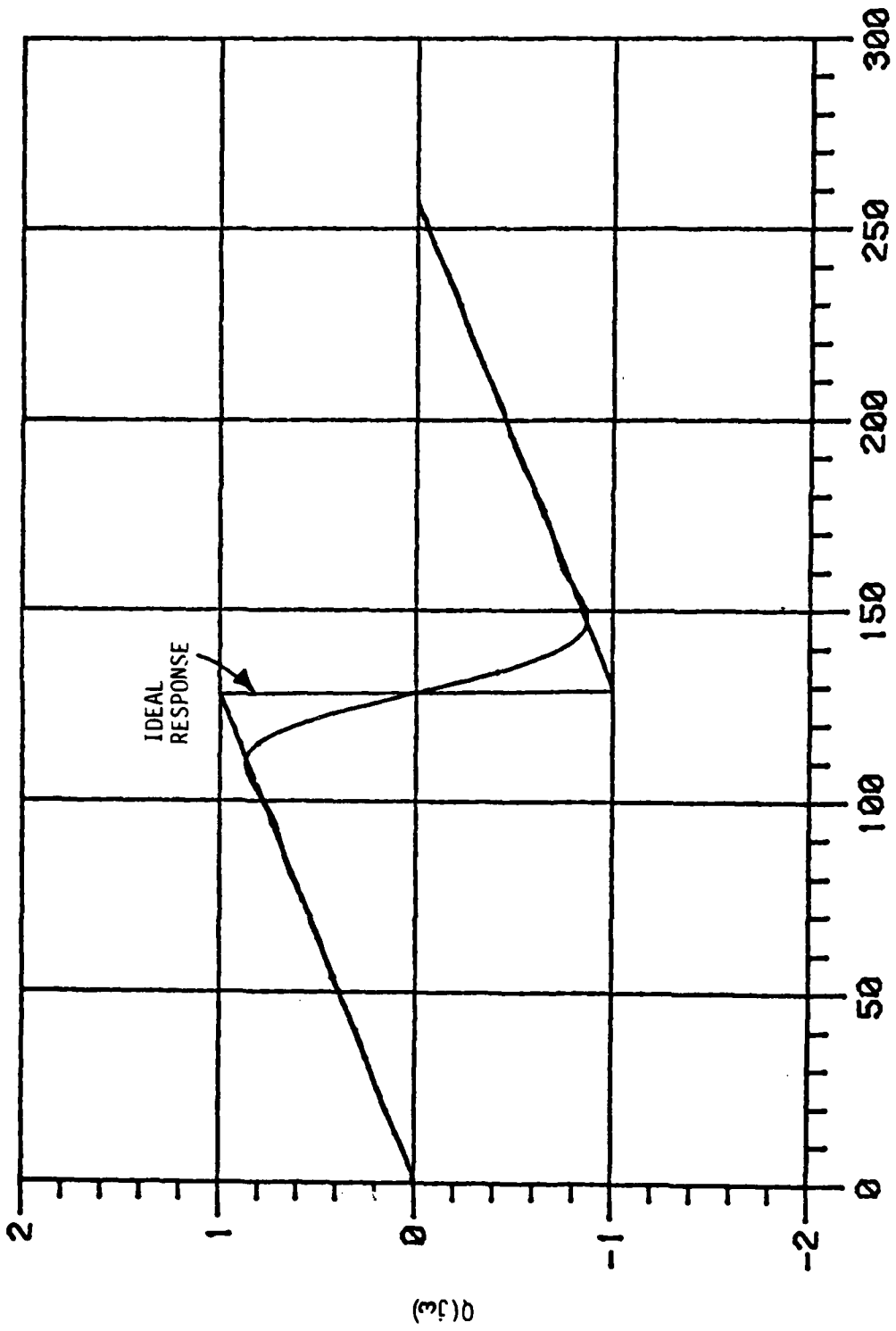


FIGURE 3-8. (17 Tap) DIFFERENTIATOR RESPONSE WITH WINDOW

3.4.3 Hilbert Transformer

The frequency response of a Hilbert transformer can be defined as

$$H(j\omega) = \begin{cases} -j, & 0 \leq \omega < \omega_s/2 \\ j, & \frac{\omega_s}{2} \leq \omega < \omega_s \end{cases}$$

The discrete Fourier transform can be expressed by the impulse response

$$h(n) = \begin{cases} \frac{\sin^2(n\pi/2)}{(n\pi/2)} & n \neq 0 \\ 0 & n = 0 \end{cases}$$

The comparison between a 17 tap filter and the ideal transform is shown in Figure 3-9.

3.4.4 Equalizer for an Arbitrary Function

The transfer function of an arbitrary frequency response

$$H(j\omega) = I(j\omega) + Q(j\omega)$$

over the band of interest is considered. Since the samples are not symmetrical in any sense, the resulting tap coefficients will be complex and asymmetrical. The matching of the ideal versus 17 tap equalizer is plotted in Figure 3-10 and the resulting complex taps are tabulated in Table 3-2. Note that the equalizer taps are complex:

$$c_k = X_k + j Y_k, \quad k = 1, 2, \dots, 17$$

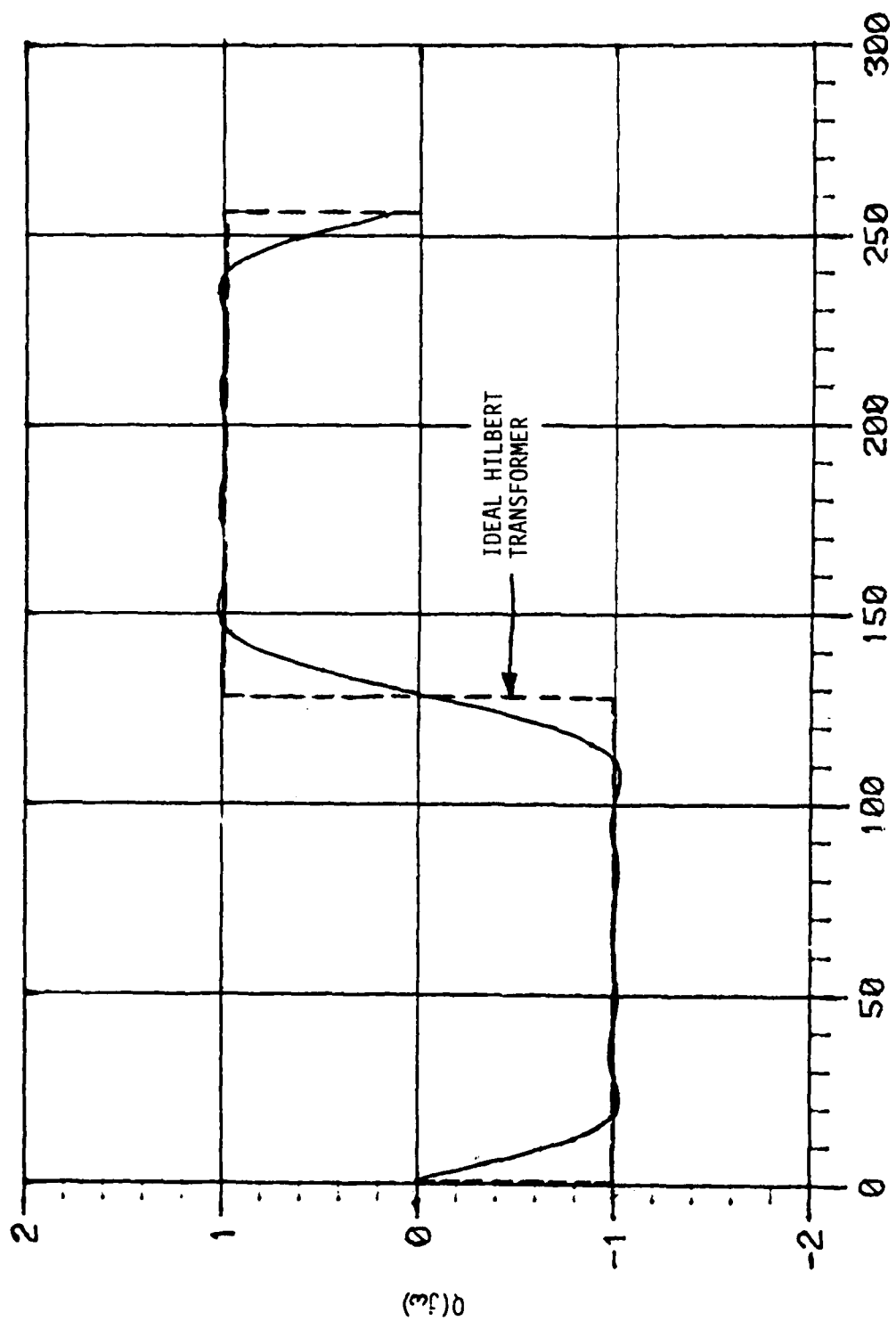


FIGURE 3-9. RESPONSE OF A (17 Tap) HILBERT TRANSFORMER (EXAMPLE 3)

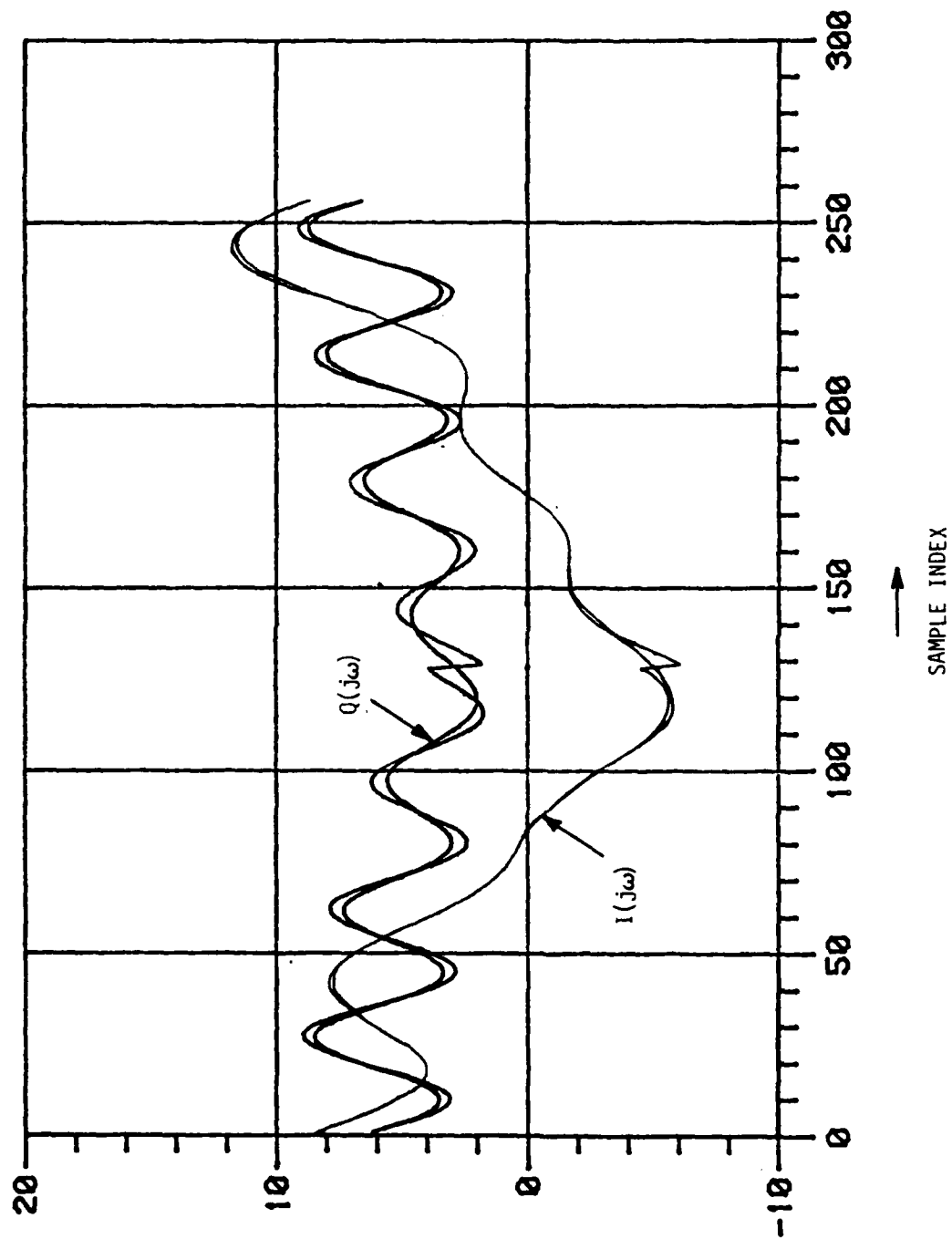


FIGURE 3-10. (17 Tap) EQUALIZER RESPONSE WITH AN ARBITRARY $I(j\omega)$ AND $Q(j\omega)$

and the gain and phase adjustment can be found by the transformation

$$g_k = 10 \times \log (x_k^2 + y_k^2)$$

$$\theta_k = \tan^{-1} (y_k/x_k)$$

TABLE 3-2. RESULTING EQUALIZER TAPS

<u>Index</u>	<u>x_i</u>	<u>y_i</u>
1	0.438043	-0.036516
2	0.931036	0.043327
3	-0.092596	-0.064665
4	0.086571	-0.686610
5	-0.074379	-0.578472
6	0.132042	-0.643479
7	-0.213581	-0.047679
8	3.133260	0.643330
9	2.183238	4.936495
10	3.120918	0.712413
11	-0.187885	-0.225917
12	0.090602	0.764618
13	-0.032419	0.508859
14	-0.005370	0.732557
15	0.036480	0.031661
16	-0.890202	-0.018254
17	-0.468842	0.016737

4. CONTROL PROGRAM

A Fast Fourier Transform (FFT) subroutine is employed to calculate the set tap coefficients for the equalizer. The equalizer taps are calculated in a recursive manner.

The input to the AMTE consists of a set of N complex correlations as a function of frequency. These samples can be expressed by the transfer function

$$H(j\omega_i) = I(\omega_i) + j Q(\omega_i), i = 1, 2, \dots, N$$

where ω_i is the i^{th} radian frequency, $I(\omega_i)$ is the in-phase frequency response, and $Q(\omega_i)$ is the quad-phase frequency response, and N is the total number of sample points.

The output of the AMTE is a set of N_t equalizer taps. For the system at hand N_t is set equal to 17. These complex tap coefficients are obtained by a truncated Fourier series coefficients. The output tap coefficient will be presented by its magnitude setting (in dB's) and phase setting in degrees.

4.1 FLOW CHART

A simplified flow chart of the main routine is shown in Figure 4-1.

4.2 PROGRAM IMPLEMENTATION

The program is implemented on the RADC HP 2100, with the operating system configured on 2/6/81. The steps to be taken for execution of the program are:

After the logs on the HP 2100, the system will return the prompt sign ":". At this level, it is necessary to link the compiled version of the program \$ZA::45. To link, one gives the command:

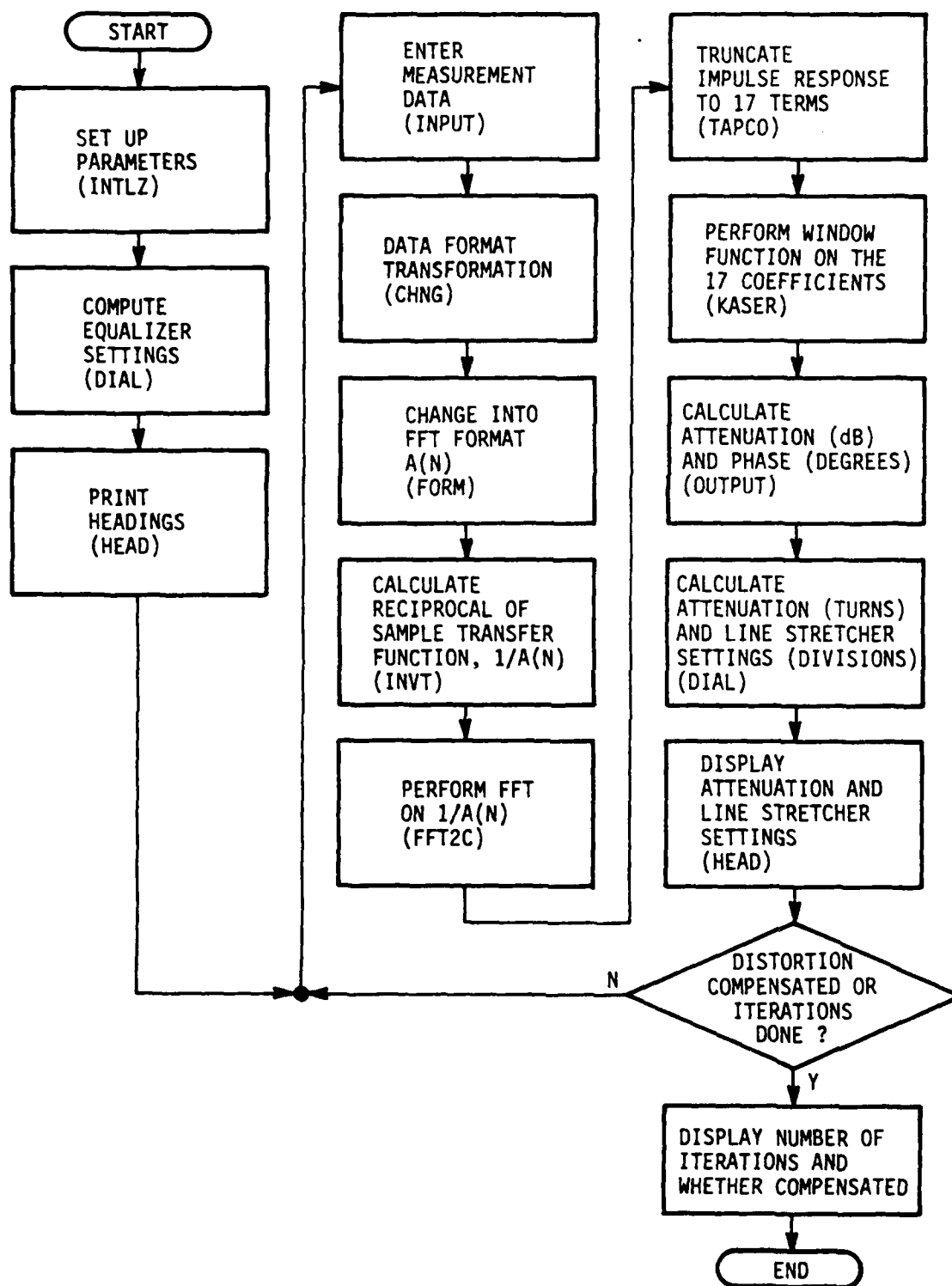


FIGURE 4-1. PROGRAM FLOW CKART

OF, AIL <CR>

Then after computer responds with ":" then type

RU, LOADR, XX <CR>

where XX is the peripheral number of the user's terminal (this may be optional) and <CR> is the carriage return key

The computer responds by giving a prompt of "/LOADR:". After this prompt, the user types:

RE, . ZA <CR>

The computer then lists the main line and the subroutines and functions called for by the user's program, in this case, \$ZA::45 while linking them together. When the computer is through linking these together, it comes back with another "/LOADR:". The user should then type

/E <CR>

The computer then links and lists on the user's terminal as it is linking, library routines and functions necessary for executing the user's program. The computer then comes back with:

"XX PAGES RELOCATED" "XX PAGES REQ'D"

"NO PAGES EMA" "NO PAGES MSEG"

"/LOADR:XX READY AT XX (date, time)"

"LOADR· \$END and it gives a ":" prompt

At the prompt, the user should run the program that has been loaded and linked, now called "AIL:". The command is:

"RU, AIL" <CR>

The computer then outputs any messages and data from the program, as it is running. The sequence of output should be:

INITIAL SETTINGS AT STEP 0 SHOULD BE...

ENTER THE FILE NAME

At this point, the user types in the name of the input file (containing a distorted sinusoid, if created by AT10 as described), for example we could use AD000, one input file from AT10; to use AD000 one types "AD000" (return)

after the message "ENTER THE FILE NAME".

The computer then prints out this message:

INTERMEDIATE SETTINGS AT STEP 1 ARE:

The computer then prints out the attenuator and the line stretcher values for the equalizer, then continues.

If the distortion has not been compensated in the first iteration, the program goes back to subroutine INPUT. The program repeats this loop 10 times, or until the distortion is less than a threshold set to be -45 dB, whichever comes first. When the program reaches the point of exiting the loop, it prints out either:

"AFTER 10 ITERATIONS DISTORTION CANNOT BE COMPENSATED"

or:

"DISTORTION COMPENSATED AFTER XX ITERATIONS"

then:

"AIL: STOP"

The computer then returns to the system level, and the user can perform other tasks, or sign off.

A sample run of the program implemented with input data is contained in Appendix 1.

4.3 COMPUTER SUBROUTINES

The following discussion includes the entry points, input arguments and output arguments of each subroutine in the AMTE program, and what the subroutines or functions accomplish.

1: Subroutine INTLZ (DMY1, DMY2, N, NTAP, BETA, IIO, IO, KSW)
initializes constants and arrays.

Input: None

Output: DMY1, DMY2, N, BETA, IO, KSW

DMY1 A Initial attenuator (dB) setting

DMY2 B Initial phase (degrees) setting

N Number of points to be transformed

NTAP Number of taps

BETA Constant used in KASER subroutine

IO Output device number

KSW Format Flag

KSW = 0: the data is expressed in decimal form

KSW = 1: the data is expressed in octal form

IIO Input device number (mag tape drive)

2: Subroutine DIAL (NTAP, DMY1, DMY2, X, Y)

This subroutine calculates attenuator and line stretcher settings.

Input: NTAP, DMY1, DMY2

DMY1, DMY2 - updated attenuation (dB) and phase (degrees)

Output: X, Y

X updated line stretcher (division) settings

Y updated attenuation (dB) settings

3: Subroutine Head (X,Y,NTAP, ISW, ICNT, IO)

This subroutine displays attenuator and line stretcher settings.

Input: X, Y, NTAP, ISW, ICNT, IO

X, Y line stretcher and attenuation settings

NTAP number of taps

ISW ISW = 0; sidelobe distortion < -45 dB

ISW = 1; at least one sidelobe > -45 dB

ICNT iteration counter

4. Subroutine INPUT (N, IBUF, IIO, IO, KSW)

INPUT defines input array of in-phase and quadrature-phase data.

Input: N, IIO, IO, KSW, file name

File Name file on which the data is stored

Output: IBUF

IBUF an array containing both I & Q data in octal form

5. Subroutine CHNG (N, IBUF)

This routine swaps the upper half of the FFT input array with the lower half.

Input: N, IBUF

Output: IBUF

6. Subroutine FORM (N, IBUF, A)

FORM will compute complex array $A = I + jQ$ and also gain = $5 \log_{10} (I^2 + Q^2)$ and phase = $\tan^{-1} (Q/I)$

Input: N, IBUF

Output: A

7. Subroutine INVT (N,A)

This subroutine computes the sequence to be equalized:

$$A_i = \frac{1}{A_i} \text{ where } i = 1, 2, 3, \dots, N$$

Input: N, A

Output: A

8. Subroutine FFT2C (A, M, IMK) computes the Fourier transform of the input array A

Input: M, A

Output: A

9. Subroutine TAPCO (N, A, NTAP, COEF, IO)

TAPCO truncates array A(N) into finite terms. The number of terms is defined as NTAP (number of taps) to specify an equalizer. The variable IO is a device number for the output which is normally computer-dependent. The resulting equalizer taps are stored in COEF (NTAP).

10. Subroutine KASER (NTAP, BETA, COEF, IO)

This subroutine applies the KAISER window function to the truncated Fourier transform output COEF (NTAP). A functional subroutine BESSL (X) is required to compute the window parameters. BESSL is the modified Bessel function of the first kind with zero order. The argument for the BESSL is X.

11. Subroutine OUTPT (DMY1, DMY2, COEF, NTAP, ISW)

Subroutine OUTPT computes updated attenuation (dB) and phase shift (degrees).

$$X_i = 20 \log_{10} (10^A); A = \frac{DMY1_i}{20} + 1$$

$$Y_i = 20 \log_{10} (10^B); B = \frac{ATT_i}{20} + 1$$

$$\text{updated attenuation}_i = 20 \log_{10} (10^C)$$

$$\text{where } C = \frac{X_i + Y_i}{20} + 1$$

and $i = 1, 2, \dots, N$

DMY1 - previous attenuation (dB)

ATT - present tap indication (dB)

$$\text{phase shift} = \sum_{i=1}^{i=N} \text{phase}_i$$

Input: DMY1, DMY2, COEF, NTAP

DMY1 - updated attenuation setting (dB)

DMY2 - updated phase shift setting (degrees)

ISW - ISW = 0; sidelobe distortion < -45 dB

ISW = 1; at least one sidelobe > -45 dB

12: Subroutine DIAL (NTAP, DMY1, DMY2, ISW, ICNT, IO)

DIAL was described previously.

13: Subroutine HEAD (X, Y, NTAP, ISW, ICNT, IO)

HEAD was described previously.

14: Subroutine END (ISW, ICNT, IO)

This subroutine will print a message depending on what the inputs are:

Input: ISW, ICNT, IO

Output: If ISW = 0, message is "Distortion compensated after so many iterations"

If ICNT = 10, message is "After 10 iterations distortion cannot be compensated"

15: Function ZLOG2: This function calculates log to the base 10 of the input quantity X. It takes the natural log (ALOG) of X and multiplies by Y, where $Y = 1/\log_e 10$.

16: Function ZN1: This calculates arctangent of input quantity (in radians).

4.4 COMPUTER PROGRAM LISTING

The following is a listing of the computer program:

```

0001  FTN4
0002  C    REVISED FILE 1/22/81
0003      PROGRAM AIL
0004      COMPLEX A(256),B(256),COEF(256)
0005      DIMENSION IBUF(256),DMY1(17),DMY2(17),X(17),Y(17)
0006      DIMENSION INK(9)
0007      ICNT=0
0008      M=8
0009  C          INITIALIZE CONSTANTS
0010      CALL INTLZ (DMY1,DMY2,N,NTAP,BETA,IIO,IO,KSQ)
0011  C          CALCULATE INITIAL ATTENUATOR AND LINE STRETCHER SETTING
0012      CALL DIAL(NTAP,DMY1,DMY2,X,Y)
0013  C          DISPLAY ATTENUATOR AND LINE STRETCHER SETTINGS
0014      CALL HEAD (X,Y,NTAP,ISW,ICNT,IO)
0015      DO 10 I= 1,10
0016      ICNT= I
0017      IF (ICNT.EQ.8) GO TO 20
0018  C          ENTER SAMPLE TRANSFER FUNCTION AS I AND Q DATA
0019      CALL INPUT(N,IBUF,IIO,IO,KSQ)
0020  C          SHIFT DATA N/2 SAMPLES
0021      CALL CHNG(N,IBUF)
0022  C          COMPUTE TRANSFER FUNCTION A(N)=I(N)+JQ(N)
0023      CALL FORM(N,IBUF,A)
0024  C          COMPUTE EQUALIZER TRANSFER FUNCTION 1/A(N)
0025      CALL INVT(N,A)
0026  C          PERFORM FFT ON A
0027      CALL FFT2C(A,M,INK)
0028  C          TRUNCATE THE IMPULSE RESPONSE TO 17 TERMS
0029      CALL TAPCO (N,A,NTAP,COEF,IO)
0030  C          PERFORM WINDOW FUNCTION ON TRUNCATED SERIES
0031      CALL KASER (NTAP,BETA,COEF)
0032  C          CALCULATE ATTENUATION (DB) AND PHASE SHIFT (DEGREES)
0033      CALL OUTPT (DMY1,DMY2,COEF,NTAP,ISW)
0034  C          CALCULATE ATTENUATION (TURNS) AND LINE STRETCHER SETTINGS
0035      CALL DIAL(NTAP,DMY1,DMY2,X,Y)
0036  C          DISPLAY ATTENUATION AND LINE STRETCHER SETTINGS
0037      CALL HEAD (X,Y,NTAP,ISW,ICNT,IO)
0038      IF (ISW.EQ.0) GO TO 20
0039  10  CONTINUE
0040  C          DISPLAY AFTER HOW MANY ITERATIONS DISTORTION WAS
0041  C          COMPENSATED ,OR THAT IT WAS NOT COMPENSATED AFTER A
0042  C          GIVEN NUMBER OF ITERATIONS.
0043  20  CALL END (ISW,ICNT,IO)
0044  9998 WRITE(37,99980)
0045  99980 FORMAT(" AIL : STOP")
0046      END

```

```

0047 C
0048 C
0049 C      CALCULATE LOG TO THE BASE 10
0050 FUNCTION ZLOG1 (X)
0051 Y=0.4342944819
0052 IF (X.LE.0.)X=1.E-10
0053 ZLOG1=Y*ALOG(X)
0054 RETURN
0055 END
0056 C
0057 C      CALCULATE ARCTANGENT
0058 C
0059 FUNCTION ZN2(Y,X)
0060 IF (X.EQ.0.)X=1.E-10
0061 PI=3.141592654
0062 Z=Y/X
0063 ZN2=ATAN(Z)
0064 IF (X.LT.0) ZN2=ZN2+PI
0065 C WRITE (37,976) Z,ZN2
0066 976 FORMAT (1X,E12.5,1X,E12.5)
0067 RETURN
0068 END
0069 C
0070 C
0071 C      CALCULATE BESSEL FUNCTION OF THE FIRST KIND WITH 0 ORDER
0072 FUNCTION BESSL(X)
0073 Y=X/2
0074 DELTA=1E-8
0075 E=1.
0076 DE=1.
0077 DO 1 I=1,25
0078 DE=DE+Y/FLOAT(I)
0079 SDE=DE*DE
0080 E=E+SDE
0081 IF (E*DELTA.GT.SDE)GOTO 10
0082 1 CONTINUE
0083 10 BESSL=E
0084 RETURN
0085 END

```

```

0086 C
0087 C
0088 C          SWAP THE UPPER HALF OF THE ARRAY WITH THE LOWER HALF
0089 SUBROUTINE CHNG(N,IBUF)
0090 INTEGER IBUF(1),IBUF1(300)
0091     K1=(N+1)/2
0092     K2=K1-1
0093     K=N/2
0094     DO 10 I=K1,N
0095         J=I-K
0096         IBUF1(J)=IBUF(I)
0097     10 CONTINUE
0098     DO 20 I=1,K
0099         J=I+K1
0100         IBUF1(J)=IBUF(I)
0101     20 CONTINUE
0102     DO 30 I=1,N
0103         IBUF(I)=IBUF1(I)
0104     30 CONTINUE
0105 998 FORMAT (1X,12(I6,1X))
0106     ZX=1
0107     CALL TYPE(ZX)
0108     RETURN
0109     END

```

```

0110 C
0111 C      PERFORM POLYNOMIAL FUNCTION TO CONVERT FROM ATTENUATION (DB)
0112 C      TO ATTENUATION (DIAL TURNS) AND FROM PHASE SHIFT (DEGREES)
0113 C      TO LINE STRETCHER SETTINGS (DIVISIONS)
0114 C
0115 C      SUBROUTINE DIAL (NTAP,DMY1,DMY2,X,Y)
0116 C      DIMENSION A0(17),A1(17),A2(17),A3(17),
0117 C      1DMY1(1),DMY2(1),X(1),Y(1)
0118 C      DATA A0/- .9102,- .7261,- .9251,- .6881,- .8607,- 1.2297,
0119 C      1-1.1216,- 1.1216,0.,-.8644,- .8416,- 1.0381,- .9169,
0120 C      2-2.1413,- .8422,- 1.0342,- .7343/
0121 C      DATA A1/- .1166,- .07388,- .1116,- .06238,- .1026,- .12932,
0122 C      1-.1075,- .1075,0.,-.08205,- .07806,- .1176,- .0946,- .1399,
0123 C      2-.05173,- .1192,- .07771/
0124 C      DATA A2/- .0009174,.001295,- .0003383,.001829,.0003621,
0125 C      1.00007163,- .0003624,- .0003624,0.,.0003096,- .0002862,
0126 C      2-.00003543,.000672,.0006742,.002387,- .001177,.001285/
0127 C      DATA A3/- .0000383797,.00000377,- .00002436,.000011075,
0128 C      1-.0000212,- .000033318,- .00002773,- .00002773,0.,-.000025096,
0129 C      2-.00002957,- .0000273,- .000016696,- .00001571,.00001276,
0130 C      3-.00004344,- .000008216/
0131 C      DO 10 I=1,NTAP
0132 C      J=1
0133 C      IF (I.LE.8) J=9-I
0134 C      Y1=A0(I)+A1(I)*DMY1(J)+A2(I)*DMY1(J)*DMY1(J)
0135 C      Y2=A3(I)*DMY1(J)*DMY1(J)*DMY1(J)
0136 C      Y(I)=Y1+Y2
0137 C      X(I)=DMY2(J)*3.634/(360.*1.091)
0138 C      IF (Y(I).LT.0.0) Y(I)=0.0
0139 C      IF (Y(I).GT.10.0) Y(I)=10.0
0140 C      IF (X(I).LT.0.0) X(I)=0.0
0141 C      IF (X(I).GT.11.0) X(I)=11.0
0142 C      10 CONTINUE
0143 C      WRITE (37,979) (X(I),I=1,NTAP)
0144 C      WRITE (37,979) (Y(I),I=1,NTAP)
0145 C      979 FORMAT (1X,4(E12.5,1X,E12.5,1X))
0146 C      ZX=2
0147 C      CALL TYPE (ZX)
0148 C      RETURN
0149 C      END

```

```

0150 C
0151 C
0152 C      PRINT OUT WHETHER DISTORTION IS COMPENSATED AFTER THE
0153 C      LAST ITERATION
0154      SUBROUTINE END(ISW,ICNT,ID)
0155      IF (ISW.EQ.0) GO TO 10
0156      WRITE(37,20) ICNT
0157 20  FORMAT(/,3X,5HAFTER,13,31H ITERATIONS DISTORTION CAN NOT,
0158 114HBE COMPENSATED,/)
0159      GO TO 30
0160 10  CONTINUE
0161      ICNT=ICNT-1
0162      WRITE(37,40) ICNT
0163 40  FORMAT(/,3X,28HDISTORTION COMPENSATED AFTER,12,11HITERATIONS
0164 30  CONTINUE
0165      ZX=3
0166      CALL TYPE(ZX)
0167      RETURN
0168      END
0169 C
0170 C
0171 C
0172      SUBROUTINE FORM(N,IBUF,A)
0173      COMPLEX A(1)
0174      DIMENSION IBUF(1)
0175  C      COMPUTE COMPLEX ARRAY A=I+JQ
0176      DO 10 I=1,N
0177      IA1=IBUF(I)/256
0178      IB1=IBUF(I)-256*IA1
0179      IF (IA1.GE.128) IA1=IA1-256
0180      IF (IB1.GE.128) IB1=IB1-256
0181      XI=FLOAT(IA1)/128.
0182      XQ=FLOAT(IB1)/128.
0183      A(I)=CMPLX(XI,XQ)
0184 10  CONTINUE
0185 998  FORMAT (1X,4(E12.5,1X,E12.5,1X))
0186      ZX=4
0187      CALL TYPE(ZX)
0188      RETURN
0189      END
0190 C

```

```

0191 C
0192 SUBROUTINE HEAD (X,Y,NTAP,ISM,ICNT,IO)
0193 DIMENSION X(1),Y(1),ZA(17)
0194 DATA ZA/4H1 A=,4H2 A=,4H3 A=,4H4 A=,4H5 A=,4H6 A=,4H7 A=,
0195 14H8 A=,4H M =,4H1 B=,4H2 B=,4H3 B=,4H4 B=,4H5 B=,4H6 B=,
0196 14H7 B=,4H8 B=/
0197 WRITE(37,145)
0198 145 FORMAT(1H1)
0199 ICNT1=ICNT+1
0200 GO TO (10,20,20,20,20,20,20,20,20,20,30) ICNT1
0201 10 CONTINUE
0202 WRITE(37,150) ICNT
0203 C DISPLAY ATTENUATION AND LINE STRETCHER SETTINGS
0204 150 FORMAT(/,18X,25HINITIAL SETTINGS AT STEP ,I1,11H SHOULD BE:
0205 GO TO 205
0206 20 CONTINUE
0207 ISM1=ISM+1
0208 GO TO (30,200) ISM1
0209 200 CONTINUE
0210 WRITE(37,155) ICNT
0211 155 FORMAT(/,18X,29HINTERMEDIATE SETTINGS AT STEP ,I2,5H ARE: )
0212 GO TO 205
0213 30 CONTINUE
0214 WRITE(37,160) ICNT
0215 160 FORMAT(/,21X,23HFINAL SETTINGS AT STEP ,I2,5H ARE: )
0216 205 CONTINUE
0217 WRITE(37,965)
0218 965 FORMAT (/,10X,17HATTENUATOR(TURNS),31X,19HLINE STRETCHER(DIV
0219 DO 210 I=1,NTAP
0220 WRITE(37,170) ZA(I),Y(I),ZA(I),X(I)
0221 170 FORMAT(10X,A4,F6.3,34X,A4,F4.1)
0222 210 CONTINUE
0223 ZX=5
0224 CALL TYPE (ZX)
0225 RETURN
0226 END
0227 C

```

```

0228 C
0229 SUBROUTINE INPUT(N,IBUF,IID,IO,KSW)
0230 DIMENSION IDCB(256),NAM(3),IBUF(256)
0231 DIMENSION IBUF0(128),IBUF1(128)
0232 WRITE(37,10)
0233 10 FORMAT(/,' ENTER THE FILE NAME ')
0234 READ(37,15)NAM
0235 15 FORMAT(A2)
0236 IL=N
0237 CALL OPEN(IDCB,IERR,NAM)
0238 IF(IERR.LT.0)GO TO 900
0239 C ENTER DATA IN OCTAL FORMAT
0240 CALL READF(IDCB,IERR,IBUF0)
0241 CALL READF(IDCB,IERR,IBUF1)
0242 IF(IERR.LT.0)GO TO 910.
0243 CALL CLOSE(IDCB,IERR)
0244 C FILL ARRAY WITH IN-PHASE AND QUADRATURE-PHASE COMPONENTS
0245 DO 60 J=1,128
0246 IBUF(J)=IBUF0(J)
0247 60 CONTINUE
0248 DO 70 K=1,128
0249 IBUF(K+128)=IBUF1(K)
0250 70 CONTINUE
0251 998 FORMAT (1X,12(16,1X))
0252 GO TO 999
0253 900 WRITE(37,30)IERR
0254 30 FORMAT(/,' FMP ERROR "14')
0255 GO TO 999
0256 910 WRITE(37,20)
0257 20 FORMAT(/,' ERROR READING THE FILE ')
0258 999 ZX=6
0259 CALL TYPE(ZX)
0260 RETURN
0261 END
0262 C

```

```

0263 C
0264 C      INITIALIZE CONSTANTS AND ARRAY
0265      SUBROUTINE INTLZ(DMY1,DMY2,N,NTAP,BETA,IIO,KSW)
0266      DIMENSION DMY1(1),DMY2(1),A(17),B(17)
0267      DATA A/-59.964,-59.964,-51.072,-56.743,-77.661,-60.551,
0268      1-72.714,-57.353,0.,-58.449,-62.143,-55.373,-57.741,
0269      2-54.419,-69.504,-57.047,-58.965/
0270      DATA B/659.23,756.49,810.53,983.44,162.1,399.86,
0271      1670.03,859.16,443.09,129.68,399.86,561.96,778.1,
0272      254.04,151.3,345.82,670.03/
0273      N=256
0274      NTAP=17
0275      DO 10 I=1,NTAP
0276      DMY1(I)=A(I)
0277      DMY2(I)=B(I)
0278 10    CONTINUE
0279      BETA=1.0
0280      IIO=37
0281      IO=37
0282 C      FOR DECIMAL I&O,KSW=0
0283 C      FOR OCTAL I&O,KSW=1
0284      KSW=1
0285      ZX=7
0286      CALL TYPE(ZX)
0287      RETURN
0288      END
0289 C

```

```

0290 C
0291 C          CALCULATE THE RECIPROCAL OF THE TRANSFER FUNCTION
0292 SUBROUTINE INVT(N,A)
0293 COMPLEX A(1)
0294 DO 10 I=1,N
0295 A(I)=1./ (A(I)*FLOAT(N))
0296 10 CONTINUE
0297 C      WRITE (37,998) (A(I),I=1,N)
0298 998 FORMAT (1X,4(E12.5,1X,E12.5,1X))
0299 ZX=8
0300 CALL TYPE(ZX)
0301 RETURN
0302 END
0303 C
0304 C
0305 C          APPLY KAISER WINDOW FUNCTION TO SMOOTH OUT THE RIFPLE DUE
0306 C          TO TRUNCATION OF THE FOURIER SERIES
0307 SUBROUTINE KASER(N,B,C)
0308 COMPLEX C(1)
0309 IF(B.EQ.0.0)GO TO 9999
0310 NV2=(N+1)/2
0311 DO 10 I=1,N
0312 Z2=FLOAT(I-NV2)/FLOAT(N/2)
0313 Z3=B*SQRT(1.-Z2*Z2)
0314 C(I)=C(I)*BESSL(Z3)/BESSL(B)
0315 10 CONTINUE
0316 C      WRITE (37,979) (C(I),I=1,N)
0317 979 FORMAT (1X,4(1X,E12.5,1X,E12.5))
0318 9999 ZX=9
0319 CALL TYPE(ZX)
0320 RETURN
0321 END
0322 C

```

```

0323 C
0324 SUBROUTINE OUTPT(DMY1,DMY2,COEF,NTAP,ISW)
0325 COMPLEX COEF(1)
0326 DIMENSION DMY1(1),DMY2(1),ATT(17),PHS(17)
0327 DO 10 I=1,NTAP
0328 XR=REAL(COEF(I))
0329 XI=AIMAG(COEF(I))
0330 C COMPUTE ATTENUATION OF DISTORTION
0331 AA=XR*XR+XI*XI
0332 ATT(I)=10.*ZLOG1(AA)
0333 C COMPUTE THE PHASE SHIFT OF TAP COEFFICIENTS
0334 PHS(I)=2*2.5*(XI/XR)*45./ATAN(1.)
0335 ZZ=2*2.5*(XI/XR)
0336 C WRITE (37,978) PHS(I),ZZ
0337 978 FORMAT (1X,E12.5,1X,E12.5)
0338 10 CONTINUE
0339 DO 20 I=1,NTAP
0340 ATT(I)=ATT(I)-ATT(9)
0341 PHS(I)=PHS(I)-PHS(9)
0342 20 CONTINUE
0343 ISW=0
0344 NTAP1=NTAP-1
0345 DO 30 I=1,NTAP1
0346 J=I
0347 IF (1.6E.9) J=I+1
0348 IF (ATT(J).LE.-45.) GO TO 15
0349 ISW=1
0350 GO TO 30
0351 15 CONTINUE
0352 ISW=ISW
0353 30 CONTINUE
0354 IF (ISW.EQ.0) GO TO 40
0355 DO 50 I=1,NTAP
0356 X=20.*ZLOG1((10.*+(DMY1(I)/20.))+1)
0357 Y=20.*ZLOG1((10.*+(ATT(I)/20.))+1)
0358 DMY1(I)=20.*ZLOG1((10.*+((X+Y)/20.))-1)
0359 DMY2(I)=DMY2(I)+PHS(I)
0360 50 CONTINUE
0361 40 CONTINUE
0362 WRITE (37,996)
0363 996 FORMAT (1X,14HATTENUATOR (DB),37X,19HLINE STRETCHER (DEG),/)
0364 1888 ZX=10
0365 DO 881 I=1,NTAP
0366 WRITE (37,977) DMY1(I),DMY2(I)
0367 977 FORMAT (1X,E12.5,37X,E12.5)
0368 881 CONTINUE
0369 979 FORMAT (1X,4(1X,E12.5,1X,E12.5))
0370 CALL TYPE(ZX)
0371 RETURN
0372 END
0373 C

```

```

0374 C
0375 SUBROUTINE TAPCO(N,A,NTAP,COEF,IO)
0376 COMPLEX A(1),COEF(1)
0377 NV2=(NTAP+1)/2
0378 NV21=N+NV2+1
0379 NV1=NV2+1
0380 C TRUNCATE THE ARRAY A(N) INTO A GIVEN NUMBER(NTAP) OF
0381 C TERMS
0382 DO 20 I=1,NV2
0383 J=NV2-I+1
0384 COEF(I)=A(J)
0385 20 CONTINUE
0386 C OBTAIN THE UPPER HALF OF THE COEFFICIENTS CENTERED
0387 C AROUND (NTAP+1)/2
0388 DO 30 I=NV1,NTAP
0389 J=NV21-I
0390 COEF(I)=A(J)
0391 30 CONTINUE
0392 C WRITE (37,979) (COEF(I),I=1,NTAP)
0393 979 FORMAT (1X,4(1X,E12.5,1X,E12.5))
0394 ZX=11
0395 CALL TYPE(ZX)
0396 RETURN
0397 END

```

```

0398 C
0399 C
0400 SUBROUTINE FFT2C (A,M,IWK)
0401 INTEGER M,IWK(1)
0402 COMPLEX A(1)
0403 C
0404 C
0405 INTEGER I,ISP,J,JJ,JSP,K,K0,K1,K2,K3,KB,KN,MK,MM,MP,N,
0406 1 N4,N8,N2,LM,NN,JK
0407 REAL RAD,C1,C2,C3,S1,S2,S3,CK,SK,SQ,A0,A1,A2,A3,
0408 1 B0,B1,B2,B3,TWOPI,TEMP,
0409 C 2 ZERO,ONE,Z0(2),Z1(2),Z3(2)
0410 2 ZERO,ONE,Z0(2),Z1(2),Z3(2),Z2(2)
0411 COMPLEX ZA0,ZA1,ZA2,ZA3,AK2
0412 EQUIVALENCE (ZA0,Z0(1)),(ZA1,Z1(1)),(ZA2,Z2(1)),
0413 1 (ZA3,Z3(1)),(A0,Z0(1)),(B0,Z0(2)),(A1,Z1(1)),
0414 2 (B1,Z1(2)),(A2,Z2(1)),(B2,Z2(2)),(A3,Z3(1)),
0415 3 (B3,Z3(2))
0416 DATA SQ/.707106781/
0417 DATA SK/.382683432/
0418 DATA CK/.923879533/
0419 DATA TWOPI/6.28318531/
0420 DATA ZERO/0.0/,ONE/1.0/
0421 MP = M+1
0422 N = 2**M
0423 IWK(1) = 1
0424 MM=(M/2)*2
0425 KN = N+1
0426 DO 5 I=2,MP
0427 IWK(I) =IWK(I-1)+IWK(I-1)
0428 5 CONTINUE
0429 RAD = TWOPI/N
0430 MK = M - 4
0431 KB = 1
0432 IF (MM .EQ. M) GO TO 15
0433 K2 = KN
0434 K0 = IWK(MM+1) + KB
0435 10 K2 = K2 - 1
0436 K0 = K0 - 1
0437 AK2 = A(K2)
0438 A(K2) = A(K0) - AK2
0439 A(K0) = A(K0) + AK2
0440 IF (K0 .GT. KB) GO TO 10
0441 15 C1=ONE
0442 S1 = ZERO
0443 JJ = 0
0444 K = MM - 1

```

```

0445      J = 4
0446      IF (K .GE. 1) GO TO 30
0447      GO TO 70
0448  20    IF (IWK(J) .GT. JJ) GO TO 25
0449      JJ = JJ - IWK(J)
0450      J = J - 1
0451      IF (IWK(J) .GT. JJ) GOTO 25
0452      JJ=JJ-IWK(J)
0453      J=J-1
0454      K = K + 2
0455      GO TO 20
0456  25    JJ = IWK(J) + JJ
0457      J = 4
0458  30    ISP = IWK(K)
0459      IF (JJ .EQ. 0) GO TO 40
0460      C2 = JJ * ISP * RAD
0461      C1 = COS(C2)
0462      S1 = SIN(C2)
0463  35    C2 = C1 * C1 - S1 * S1
0464      S2 = C1 * (S1 + S1)
0465      S3 = C2 * C1 - S2 * S1
0466      S3= C2 * S1 + S2 * C1
0467  40    JSP = ISP + KB
0468  C      WRITE (37,997) S1,S2,S3
0469  C      WRITE (37,997) C1,C2,C3
0470      DO 50 I = 1 , ISP
0471      K0 = JSP - I
0472      K1 = K0 + ISP
0473      K2 = K1 + ISP
0474      K3 = K2 + ISP
0475      ZA0 = A(K0)
0476      ZA1 = A(K1)
0477      ZA2 = A(K2)
0478      ZA3 = A(K3)
0479      IF (S1 .EQ. ZERO) GO TO 45
0480      TEMP = A1

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```

0481      A1 = A1 * C1 - B1 * S1
0482      B1 = TEMP * S1 + B1 * C1
0483      TEMP = A2
0484      A2 = A2 * C2 - B2 * S2
0485      B2 = TEMP * S2 + B2 * C2
0486      TEMP = A3
0487      A3 = A3 * C3 - B3 * S3
0488      B3 = TEMP * S3 + B3 * C3
0489  45    TEMP = A0 + A2
0490      A2 = A0 - A2
0491      A0 = TEMP
0492      TEMP = A1 + A3
0493      A3 = A1 - A3
0494      A1 = TEMP
0495      TEMP = B0 + B2
0496      B2 = B0 - B2
0497      B0 = TEMP
0498      TEMP = B1 + B3
0499      B3 = B1 - B3
0500      B1 = TEMP
0501      AZ1=A0+A1
0502      AZ2=B0+B1
0503      AZ3=A0-A1
0504      AZ4=B0-B1
0505      AZ5=A2-B3
0506      AZ6=B2+A3
0507      AZ7=A2+B3
0508      AZ8=B2-A3
0509  997   FORMAT (1X,4(E12.5,1X))
0510      A(K0) = CMPLX(AZ1,AZ2)
0511      A(K1) = CMPLX(AZ3,AZ4)
0512      A(K2) = CMPLX(AZ5,AZ6)
0513      A(K3) = CMPLX(AZ7,AZ8)
0514  999   FORMAT (1X,'A COEFFICIENTS')
0515  50     CONTINUE
0516  C     WRITE (37,998) A(K0),A(K1),A(K2),A(K3)
0517  C     WRITE (37,995) K0,K1,K2,K3
0518  995   FORMAT (1X,4(I4,1X))
0519  998   FORMAT(1X,4(E12.5,1X,E12.5,1X))
0520      IF (K .LE. 1) GO TO 55

```

```

0521      K = K - 2
0522      GO TO 30
0523 55    KB = K3 + ISP
0524      IF (KN .LE. KB) GO TO 70
0525      IF (J .NE. 1) GO TO 60
0526      K = 3
0527      J = MK
0528      GO TO 20
0529 60    J = J - 1
0530      C2 = C1
0531      IF (J .NE. 2) GO TO 65
0532      C1 = C1 + CK + S1 + SK
0533      S1 = S1 + CK - C2 + SK
0534      GO TO 35
0535 65    C1 = (C1-S1) + S0
0536      S1 = (C2 + S1) + S0
0537      GO TO 35
0538 70    CONTINUE
0539 C     WRITE (37,998) (A(KZ),KZ=1,256)
0540      IF (M .LE. 1) GO TO 9005
0541      MP = M + 1
0542      JJ = 1
0543      IWK(1) = 1
0544      DO 75 I = 2,MP
0545      IWK(I) = IWK(I-1)*2
0546 75    CONTINUE
0547      N4 = IWK(MP-2)
0548      IF (M .GT. 2) N8 = IWK(MP-3)
0549      N2 = IWK(MP-1)
0550      LM = N2
0551      NN = IWK(MP) + 1
0552      MP = MP - 4
0553      J = 2

```

```

0554 80 JK = JJ + N2
0555      AK2 = A(J)
0556      A(J) = A(JK)
0557      A(JK) = AK2
0558      J = J+1
0559      IF (JJ .GT. N4) GO TO 85
0560      JJ = JJ + N4
0561      GO TO 105
0562 85  JJ = JJ - N4
0563      IF (JJ .GT. N8) GO TO 90
0564      JJ = JJ + N8
0565      GO TO 105
0566 90  JJ = JJ - N8
0567      K = MP
0568 95  IF (IWK(K) .GE. JJ) GO TO 100
0569      JJ = JJ - IWK(K)
0570      K = K - 1
0571      GO TO 95
0572 100 JJ = IWK(K) + JJ
0573 105 IF (JJ .LE. J) GO TO 110
0574      K = NN - J
0575      JK = NN - JJ
0576      AK2 = A(J)
0577      A(J) = A(JJ)
0578      A(JJ) = AK2
0579      AK2 = A(K)
0580      A(K) = A(JK)
0581      A(JK) = AK2
0582 110 J = J + 1
0583      IF (J .LE. LM) GO TO 80
0584 9005 ZX=12
0585      CALL TYPE(ZX)
0586 C      WRITE (37,998) (A(KZ),KZ=1,256)
0587      RETURN
0588      END
0589 C
0590 C
0591      SUBROUTINE TYPE(ZX)
0592 C      WRITE(37,20)ZX
0593 20  FORMAT(/, ' SUBROUTINE ENTERED ',F4.1)
0594      RETURN
0595      END

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4.5 COMPUTER SOFTWARE VERIFICATION

To assure that the software works properly, the following verification procedure has been established. Before running the program on real data, it is recommended that the program be run on an idealized, sinusoidal waveform with slight distortion added.

Two cases of distortion will be introduced; the first one involves amplitude only, and the second one involves phase only. The distortions are presented as sinusoids of various amplitudes but always small enough so as to permit the use of the paired echo theory concepts to be valid. Also, the period of the sinusoid is always harmonically related to the bandwidth of the equalizer network and as such is consistent with the concept of representing the distortion as a Fourier series.

The test cases of distortion are separated into two groups, one of which assumes only amplitude distortion and the other of which assumes only phase distortion, but of varying levels. The FFT presents the coefficients for the taps which in effect represent the amplitude and phase of the echo associated with each tap. These coefficients are then compared to the calculated values based on the paired echo theory.

CASE 1: A sinusoidal amplitude distortion of various peak to peak values.

$$|G| = 10 \log_{10} \sqrt{I^2 + Q^2} = 5 \log_{10} (I^2 + Q^2) = \text{amplitude}$$

$$\theta = \tan^{-1} \frac{Q}{I} = \text{phase}$$

To simplify, we consider the effects of only amplitude distortions so that assuming no phase distortion and letting $Q = 0$ we get

$$|G| = 5 \log_{10} I^2 = 10 \log_{10} I$$

$$\theta = \tan^{-1} \left(\frac{Q}{I} \right) = 0$$

Since a sinusoidal distortion is needed:

$$\frac{\sin(\Delta X N) - 1}{K} = 10 \log_{10} I$$

where

ΔX = incremental frequency

N = number of points

K = scale factor (for $K = 1$, numerator goes 0 to -2 or 2 dB)

and $10 \log I$ represents the distortion level in dB (peak-to-peak).

In order to fit the RADC data form so that $-128 \leq I < 128$, we multiply the given values of I by 128.

TEST 1: Amplitude distortion, 0.5 dB peak-to-peak with first echo pair

$$-0.5 = \frac{\sin(\Delta X N) - 1}{K} = 10 \log_{10} \text{ therefore } K = 4$$

For 215 points in 2π radians or 360° , there $\Delta X = \frac{360^\circ}{215}$ and $0 \leq N \leq 214^*$

$$I = 10 \left[\frac{\sin(\Delta X N) - 1}{40} \right]$$

From the test run we get the first echo peak value distortion to be -30.44 dB. Analytically (for small amp distortion) we have:

*Note that the number of sample points is not germane to the analysis (as long as it is a large number) and relates only to the expected number of samples to be used. We later change this to 256 points.

$$20 \log_{10} \left(1 + \frac{a_1}{a_0}\right) = \text{amplitude ripple in dB (peak value)}$$

$$\text{for } \frac{a_1}{a_0} \ll 1; \frac{1}{2} \frac{a_1}{a_0} = \text{peak echo amplitude}$$

$$20 \log_{10} \left(\frac{a_1}{2a_0}\right) = \text{echo in dB}$$

$$20 \log_{10} \left(1 + \frac{a_1}{a_0}\right) = 0.5 \text{ dB}$$

$$\frac{a_1}{2a_0} = \frac{10 \left[\left(\frac{0.5}{20}\right) - 1\right]}{2} = 0.0296$$

$$\text{echo} = 20 \log_{10} \left(\frac{a_1}{2a_0}\right) = -30.566 \text{ dB}$$

TEST 2: Distortion is introduced in the second echo pair with an amplitude ripple of 0.5 dB

$$I = 10 \left[\frac{(\sin \frac{\Delta x N}{40}) - 1}{40} \right]$$

$$\text{where } \Delta x = \frac{2 \times 360}{215} \text{ and } 0 \leq N \leq 215$$

From the test run we get second echo peak value to be -30.53 dB where the calculated value is the same as before -30.566 dB.

TEST 3: Distortion is introduced in the first and second echo pairs with an amplitude ripple of 0.5 dB

$$I = (10 \left[\frac{\sin (\Delta x_1 N) - 1}{40} \right] + 10 \left[\frac{\sin (\Delta x_2 N) - 1}{40} \right]) / 2$$

$$\text{where } \Delta x_1 = \frac{360}{215}; \Delta x_2 = \frac{2 \times 360}{215} \text{ and } 0 \leq N \leq 214$$

Because we are summing two sinusoidal amplitude distortions of 0.5 dB each, the resultant distortion needs to be divided by 2 in order for it to be 0.5 dB.

From the test run we get both the first and second echo peak to be -36.2 dB. The calculated first and second echo peak is:

$$20 \log_{10} \left(1 + \frac{a_1}{4a_0} \right)$$

$$\frac{a_1}{4a_0} = \frac{10 \left[\frac{0.5}{20} \right]}{4} = 0.0148$$

$$20 \log_{10} \frac{a_1}{a_0} = 36.58 \text{ dB}$$

Tests 4 through 6 are the same as Tests 1 through 3 respectively, except the peak amplitude distortion is set at 1 dB instead of 0.5 dB (then $K = 2$). Test 7 is the same as Tests 4 or 5 except the distortion is introduced into the eighth echo pair. The results are given in Table 4-1.

TEST 8: Distortion is introduced in the first and eighth echo pairs with an amplitude ripple of 1 dB ($K = 2$)

$$I = \left(10 \frac{\sin(\Delta X_1 N) - 1}{20} + 10 \frac{\sin(\Delta X_2 N) - 1}{20} \right) / 2$$

where $\Delta X_1 = \frac{360}{215}$; $\Delta X_2 = \frac{8 \times 360}{215}$ and $0 \leq N \leq 214$

CASE II; A sinusoidal phase distortion of various peak-to-peak values. As defined previously the gain and phase are:

$$|G| = 10 \log_{10} \sqrt{I^2 + Q^2}$$

$$\theta = \tan^{-1} \frac{Q}{I}$$

Now we want to have a sinusoidal phase variation, so $\theta = A \sin(\Delta X N)k$. To simplify, let us set $|G| = 0$ dB so that:

TABLE 4-1. TEST RESULTS OBTAINED WITH DEC-20 COMPUTER

	<u>Peak Ampl. Distortion (dB)</u>	<u>Echo</u>	<u>Simulated* Distortion Peak (dB)</u>	<u>Calculated Distortion Peak (dB)</u>
Test 1	0.5	1	-30.44	-30.566
Test 2	0.5	2	-30.53	-30.566
Test 3	0.5	1	-36.26	-36.58
Test 3	0.5	2	-36.27	-36.58
Test 4	1	1	-23.76	-24.29
Test 5	1	2	-23.85	-24.29
Test 6	1	1	-29.69	-30.31
Test 6	1	2	-30.04	-30.31
Test 7	1	8	-25.8	-24.29
Test 8	1	1	-29.77	-30.31
Test 8	1	8	-31.82	-30.31

*Actual Distortions outputted by the algorithm are in echo pairs.
The value shown is an average.

$$(1) \quad 10 \log_{10} [I^2 + Q^2]^{1/2} = 0 \text{ and } [I^2 + Q^2]^{1/2} = 1 \text{ or } I^2 + Q^2 = 1$$

$$(2) \quad \frac{Q}{I} = \tan (A \sin(\Delta X N) - k)$$

$$Q = I \tan (A \sin (\Delta X N) - k)$$

Let $A \sin (X N) - k = \emptyset$ so that $Q = I \tan \emptyset$

From (1) we have:

$$I^2 = 1 - Q^2$$

$$\text{From (2) } Q^2 = I^2 \tan^2 \emptyset = (1 - Q^2) \tan^2 \emptyset = \tan^2 \emptyset - Q^2 \tan^2 \emptyset$$

$$Q^2 + Q^2 \tan^2 \emptyset = \tan^2 \emptyset$$

$$Q^2 (1 + \tan^2 \emptyset) = \tan^2 \emptyset$$

$$Q = \frac{\tan \emptyset}{1 + \tan^2 \emptyset}$$

$$I = \left[\frac{1 - \tan^2 \emptyset}{1 + \tan^2 \emptyset} \right]^{1/2} = \frac{1}{(1 + \tan^2 \emptyset)^{1/2}}$$

$$\emptyset = \tan^{-1} \frac{Q}{I} = \text{phase}$$

To simplify, let us always work in the I-V quadrant so that $Q \leq 0$ and $I \geq 0$, therefore when $\tan \emptyset \leq 0$, then $1 / 1 + \tan^2 \emptyset \geq 0$. In order to fit the RADC format (2's complement) we multiply I and Q by 128.

TEST 1: Sinusoidal phase distortion of 6° peak value is introduced in the first echo pair

$$\emptyset = 3 \sin (\Delta X N) - k \text{ where } \Delta X = \frac{360}{215}, 0 \leq N \leq 214 \text{ and}$$

$k = \text{offset} = 42^\circ$ places \emptyset in fourth quadrant

$$Q = \frac{\tan(3 \sin(\Delta x N) - 42)}{\sqrt{1 + \tan^2(3 \sin(\Delta x N) - 42)}} \text{ and } I = \sqrt{1 - Q^2}$$

From computer simulation we get the first echo to be -31.49 dB.

Analytically we get

$$20 \log_{10} \left(\frac{2\pi \times b_1}{4 \times 360} \right) = \text{echo in dB}$$

where b_1 = ripple in degrees

$$b_1 = 6^\circ, 20 \log_{10} \left(\frac{12\pi}{4 \times 360} \right) = -31.64 \text{ dB}$$

TEST 2: Cosinusoidal phase distortion of 6° peak value is introduced in the first echo

$$\phi = 3 \cos(\Delta x N) - 42$$

The computer simulation is basically the same except that for an odd (sin) distortion function the phase angle for the two echoes is 180° apart, whereas for an even (cos) distortion function the two echoes are in phase. The opposite is true for amplitude distortion. That is, for odd function distortions the phase angle for the two echoes is in phase whereas for even distortion function the phase angle for the two echoes is 180° apart.

TEST 3: Sinusoidal phase distortion of 22.92° peak value is introduced in the first echo

$$\phi = 11.46 \sin(\Delta x N) - 42$$

Calculated result is $20 \log_{10} \left(\frac{2\pi \times 22.92}{4 \times 360} \right) = -20 \text{ dB}$ and the simulated result is -20.02 dB.

The results for the phase distortion test cases are shown in Table 4-2.

TABLE 4-2. TEST RESULTS OBTAINED WITH DEC-20 COMPUTER

	<u>Peak Phase Distortion (degrees)</u>	<u>Echo</u>	<u>Simulated Distortion Phase (dB)</u>	<u>Calculated Distortion Phase (dB)</u>
Test 1	6	1	-31.49	-31.64
Test 2	6	1	-31.49	-31.64
Test 3	22.92	1	-20.02	-20.0

4.5 PROGRAM TEST ON THE HP 2100A

Three tests were run on the algorithm contained in the HP 2100A computer at RADC. The first test is a single echo test involving a peak sinusoidal amplitude distortion of 0.5 dB. The second test is a double echo test involving a peak sinusoidal amplitude distortion of 0.5 dB with one sine wave at twice the frequency of the other. The third test is a single echo test involving a peak phase distortion of six degrees.

To perform the first test, a program has been implemented (now on disk cartridge 45) called "AT10". A listing of this program is given in Appendix 3.

AT10 outputs M sample points of a distorted sine wave given by:

$$I = 10 \frac{[\sin \Delta X N] - 1}{40}$$

where: $\Delta X = \frac{360^\circ}{M}$, and $N = 0, 1, 2, \dots, M$

In our case, we have run AT10 with 256 sample points ($M = 255$). As mentioned, the phase component of this test is 0. AT10 produces both the single echo pair and two pair test cases. The

case just described (one echo pair) is printed out in a data file called "AD000"; this file contains 256 octal mode (06 integers, in two records, 128 numbers each; this file is the sequential output of the "I" or amplitude function as N goes from 1 to 256.

To run the double echo-pair, amplitude-distortion-only case, we executed AT10 again but such that AT10 adds to the first waveform, a second one given by

$$I_2 = 10 \frac{\sin(\Delta X_2 N) - 1}{40}$$

where: $\Delta X_2 = \frac{2 \times 360}{M}$, and $N = 0, 1, 2, \dots, M = 255$

The superimposed waveform (this is what is printed out into the data file) is

$$I_{sup} = (I + I_2)/2$$

Again, there are 256 samples, written into two 128-number records in 06 format. The file containing I_{sup} is called "AD001". This double echo-pair that is equivalent to Test 3 of Table 4-1 which shows the theoretical peak distortion to be -36.58 dB.

For the third case, phase distortion only, the program "TEST 1" was executed. The waveform produced by "TEST 1" is a sine whose phase is given by:

$$Q = \frac{\tan(3 \sin(\Delta X_1 N) - 42)}{1 + \tan^2(3 \sin(\Delta X_1 N) - 42)}, \quad X = \frac{360}{256}, \quad N = 0, 1, 2, \dots, 255$$

To run this test case, we executed "TEST 1" (also on disk 45), and used the data file "AD002". This results in a test case of 6° phase distortion equivalent to Test 1 in Table 4-2.

Tables 4-3 through 4-5 give printouts of the data contained in the output files for these three test cases, "AD000", "AD001", and "AD002" respectively.

We can now compare the results obtained with the test cases run on the DEC-20 and HP 2100A computers with their respective equalizer algorithms. Slight differences are to be expected because of the differences in precision and the internal mathematical algorithms. Table 4-6 shows the results.

The comparison shows excellent agreement between the two equalizer algorithm outputs (DEC-20 and HP 2100A) and demonstrates that they are performing the way they are supposed to.

TABLE 4-3. OUTPUT TEST 1 (ONE ECHO PAIR)

File AD000

Tap No.	Attenuator (dB)	(Turns)	Line Stretcher	
			(deg)	(Div)
8A	-.59754E+02	9.924	.77894E+03	7.2
7A	-.57500E+02	9.133	.84826E+03	7.8
6A	-.50899E+02	9.931	.72472E+03	6.7
5A	-.54626E+02	9.280	.12426E+04	11.0
4A	-.76775E+02	9.870	.13916E+03	1.3
3A	-.57659E+02	9.054	.48888E+03	4.5
2A	-.63654E+02	8.213	.82400E+03	7.6
1A	-.30575E+02	2.894	.94832E+03	8.8
0	.95424E+01	0.000	.44309E+03	4.1
1B	-.30102E+02	2.571	.40519E+02	0.4
2B	-.58178E+02	8.552	.60589E+03	5.6
3B	-.53561E+02	9.354	.47294E+03	4.4
4B	-.57641E+02	9.961	.80104E+03	7.4
5B	-.52656E+02	9.388	.15492E+03	1.4
6B	-.68077E+02	9.716	.23711E+03	2.2
7B	-.55111E+02	9.231	.61405E+03	5.7
8B	-.58767E+02	9.938	.91032E+03	8.4

TABLE 4-4. OUTPUT TEST 2 (DOUBLE ECHO PAIR)

File AD001

Tap No.	Attenuator (dB)	(Turns)	Line Stretcher (deg)	(Div)
8A	-.58976E+02	9.646	.78231E+03	7.2
7A	-.58854E+02	9.603	.86500E+03	8.0
6A	-.50607E+02	9.816	.85919E+03	7.9
5A	-.55226E+02	9.481	.90270E+03	8.4
4A	-.74326E+02	9.505	.32962E+03	3.0
3A	-.56551E+02	8.710	.36137E+03	3.3
2A	-.36679E+02	3.518	.93857E+02	8.7
1A	-.36044E+02	3.898	.95012E+03	8.8
0	.95424E+01	0.000	.44309E+03	4.1
1B	-.35637E+02	3.589	.39872E+03	3.7
2B	-.35844E+02	2.950	.49132E+03	4.5
3B	-.52810E+02	9.094	.60045E+03	5.6
4B	-.57316E+02	9.856	.97058E+03	9.0
5B	-.53165E+02	9.563	.13478E+03	1.2
6B	-.66063E+02	9.314	.10264E+03	0.9
7B	-.56190E+02	9.654	.59731E+03	5.5
8B	-.58025E+02	9.706	.90695E+03	8.4

TABLE 4-5. OUTPUT CASE 3 (PHASE DISTORTION ONLY)

File AD004

Tap No.	Attenuator (dB)	(Turns)	Line Stretcher (deg)	(Div)
8A	-.59834E+02	9.953	.79680E+03	7.4
7A	-.59511E+02	9.837	.73877E+03	6.8
6A	-.50643E+02	9.831	.96246E+03	8.9
5A	-.56282E+02	9.841	.11579E+04	10.7
4A	-.72772E+02	9.269	.38686E+03	3.6
3A	-.57695E+02	9.066	.39645E+03	3.7
2A	-.66269E+02	8.720	.67455E+03	6.2
1A	-.31102E+02	2.984	.10384E+04	9.6
0	.95424E+01	0.000	.44309E+03	4.1
1B	-.31104E+02	2.742	.17235E+03	1.6
2B	-.58022E+02	8.500	.44508E+03	4.1
3B	-.53881E+02	9.466	.78023E+03	7.2
4B	-.57201E+02	9.818	.86518E+03	8.0
5B	-.53831E+02	9.794	.10693E+03	1.0
6B	-.68513E+02	9.803	.20575E+03	1.9
7B	-.56951E+02	9.961	.33624E+03	3.1
8B	-.57922E+02	9.674	.66682E+03	6.2

TABLE 4-6. COMPARISON OF TEST RESULTS FOR THE DEC-20 AND HP 2100A
EQUALIZER ALGORITHMS

<u>Test</u>	<u>Type of Distortion</u>	<u>Echo Affected</u>	<u>Simulated Echo Level in dB</u>		<u>Theoretical Level in dB</u>
			<u>HP 2100A</u>	<u>DEC-20</u>	
Test 1,	0.5 dB	1A	-30.58	-30.44	-30.57
One Echo Pair	Peak Amplitude Only	1B	-30.10	(AVG)	-30.57
Test 2,		1A	-36.04	36.36	-36.58
Double Echo Pair	0.5 dB	1B	-35.64	(AVG)	-36.58
		2A	-36.68		-36.58
		2B	-35.84		-36.58
Test 3,	6° Peak	1A	-31.10	-31.49	-31.64
	Phase Distortion Only	1B	-31.10	(AVG)	-31.64

While this is not 100% conclusive, it does provide a high degree of confidence that the algorithm is working properly. The only real test is the use of the algorithm over many real situations which completely exercise it. Some comments about what to expect are in order.

First of all, the Microwave Transversal Equalizer (MTE) to be used to provide corrections to the distortion has its own inherent second order distortions which are not constant. That is, under one set of amplitude and phase adjustments for each of the taps there is a given "self-distortion" which is included in the data supplied to the algorithm to analyze. When the amplitude and phase settings are now changed to correct for the total distortion reflected in the data, then the new settings of the MTE will correct much of the distortion but because the MTE settings are different from the original settings there will be a new "self-distortion" introduced by the MTE. This means that the correction is imperfect and the process must be iterated until the distortion residue is less than the allowable value (or until the "self-distortion" changes are greater than the corrected indicated by the algorithm).

Another source of distortion lies in the hardware used to provide the data samples. These distortions are:

1. the phase response of the components
2. the amplitude response of the components
3. noise introduced on the data (Gaussian)
4. random spikes (transients induced by interference)

5. sinusoidal variations (coupled interference from motors, oscillators, etc.)
6. timing errors (clocks, circuit switching speeds, etc.)
7. inaccuracies in data samples (improper scaling, etc.)
8. digitizing errors (bit errors in digital operations)

These errors introduce their own "self-distortion" and just as in the MTE limit the residual distortion that can be obtained. In addition, some of the errors are random so that iterations won't help.

Finally, there is the algorithm itself. It cannot be considered fully debugged until all combinations of operation have been exercised. This is not a practical thing to do in the laboratory but instead requires a period of field use. In addition, the algorithm has limits of precision which will ultimately limit the amount of distortion that can be corrected even if the hardware were perfect, although this is the area that is least likely to present a problem.

5. CONCLUSIONS AND RECOMMENDATIONS

Computer algorithms have been successfully developed to provide open-loop adaptive control of the MTE. The algorithms are based upon the application of FFT techniques, and the necessary corollary software programming procedures have been developed and described.

Verification of the aforementioned FFT and associated software programming has also been accomplished at AIL with a DEC-20 computer. Such verification has involved the generation of output adjustment data for MTE control based upon computer analysis of artificially simulated time sidelobe input distortion levels. A similar procedure will be undertaken at RADC using real-time I and Q data acquired at the A. Froelich High Power Tube Facility. Such distortion levels will be processed at RADC using translation of format programs between the AIL DEC-20 and the RADC HP 2100A computers. Preliminary data suggests that the post-delivery program translation will be successful after the normal debugging procedures have been completed.

AIL recommendations for future MTE related efforts include the following:

- Continuation and/or extension of contracted efforts to include AIL post-delivery support for RADC.

- Investigation and definition of suitable closed-loop techniques and procedures for adaptive operation of MTE.
- Development of suitable solid-state time delay devices to replace the present manually adjustable line stretchers.
- Modification of the MTE to expand capability by providing 32 tap operation.
- Development of suitable electronic interface to implement fully adaptive closed-loop operation of the MTE.

APPENDIX 1

SAMPLE COMPUTER RUN WITH
INPUT DATA

APPENDIX 1: SAMPLE RUN

This appendix includes a sample run of the program with the input data entitled AD0000.

:RU,AIL
1

INITIAL SETTINGS AT STEP 0 SHOULD BE:

ATTENUATOR

1 A=10.000
2 A=10.000
3 A=10.000
4 A=10.000
5 A=10.000
6 A=10.000
7 A=10.000
8 A=10.000
M = 0.000
1 B=10.000
2 B=10.000
3 B=10.000
4 B=10.000
5 B=10.000
6 B=10.000
7 B=10.000
8 B=10.000

Initial
Attenuator
Settings

LINE STRETCHER

1 A= 7.9
2 A= 6.2
3 A= 3.7
4 A= 1.5
5 A= 9.1
6 A= 7.5
7 A= 7.0
8 A= 6.1
M = 4.1
1 B= 1.2
2 B= 3.7
3 B= 5.2
4 B= 7.2
5 B= .5
6 B= 1.4
7 B= 3.2
8 B= 6.2

Initial
Line
Stretcher
Settings

APPENDIX 1 SAMPLE RUN (continued)

ENTER THE FILE NAME	(Attenuator in dB Units)		
AD000			
-.53372E+02	-.59486E+02	-.50322E+02	-.55731E+02
-.52821E+02	-.24613E+02		-.67727E+02
.95424E+01	-.23590E+02	-.50158E+02	-.54445E+02
-.64164E+02	-.56657E+02		-.55841E+02
-.57362E+02			-.53580E+02
.65446E+03	.67758E+03	.96441E+03	.92669E+03
.84035E+03	.94840E+03		.17776E+03
.44309E+03	.40437E+02	.58954E+03	.64557E+03
.35742E+03	.42473E+03		.76244E+03
.67480E+03			.11079E+03

APPENDIX 1 SAMPLE RUN (continued)

INTERMEDIATE SETTINGS AT STEP 1 ARE:

ATTENUATOR

1 A= 1.976
2 A= 6.202
3 A= 9.519
4 A= 8.486
5 A= 9.669
6 A= 9.705
7 A= 9.828
8 A= 9.434
M = 0.000
1 B= 1.573
2 B= 6.085
3 B= 9.665
4 B= 9.368
5 B= 9.707
6 B= 8.934
7 B= 9.842
8 B= 9.502

LINE STRETCHER

1 A= 8.8
2 A= 7.8
3 A= 2.9
4 A= 1.6
5 A= 8.6
6 A= 8.9
7 A= 6.3
8 A= 6.1
M = 4.1
1 B= .4
2 B= 5.5
3 B= 6.0
4 B= 7.1
5 B= 1.0
6 B= 3.3
7 B= 3.9
8 B= 6.2

AFTER 0 ITERATIONS DISTORTION CAN NOT BE COMPENSATED

AIL : STOP

Note: XD = 20 in \$AT10 when generating input for this run.

In subsequent runs, XD = 40

APPENDIX 2

PROGRAM TO GENERATE
TEST DATA

APPENDIX 2. PROGRAM TO GENERATE TEST DATA

This routine generates ideal sinusoidal distortion as the data file for the program.

```

0001  FTN4.L
0002      PROGRAM AT10
0003      DIMENSION IBUF2(256),IBUF3(256),MBUF(256)
0004      DIMENSION IDCB(272),NAM(3),IBUF0(256),ISIZE(2)
0005      DIMENSION LBUF(256),IBUF1(256)
0006      DIMENSION IDCB2(272),NAM1(3)
0007      ITYPE=2
0008      ISIZE=2
0009      ISIZE(2)=128
0010      DATA NAM/ 2HAD,2H00,2H0 /
0011      DATA NAM1/2HAD,2H00,2H1 /
0012      CALL CREAT (IDCB,IERR,NAM,ISIZE,ITYPE)
0013      CALL CREAT (IDCB1,IERR,NAM1,ISIZE,ITYPE)
0014      N=256
0015      ND=40.
0016      DX1=360./FLOAT(N-1)
0017      DX2=DX1*2.
0018      DO 30 J=1,N
0019      X=DX1*FLOAT(J-1)
0020      Y=DX2*FLOAT(J-1)
0021      X1=(10.♦♦(COSIN(X*3.1415/180.)-1)/XD)
0022      X2=(10.♦♦(COSIN(Y*3.1415/180.)-1)/XD)
0023      LBUF(J)=128*X1
0024      XM=(X1+X2)/2.
0025      MBUF(J)=128*XM
0026      IF (MBUF(J).GE.128) MBUF(J)=127
0027      MBUF(J)=256-MBUF(J)
0028      IF (LBUF(J).EQ.128) LBUF(J)=127
0029      LBUF(J)=256-LBUF(J)
0030      20  CONTINUE
0031      DO 30 I=1,128
0032      IBUF0(I)=LBUF(I)
0033      IBUF2(I)=MBUF(I)
0034      30  CONTINUE
0035      DO 40 K=1,128
0036      IBUF1(K)=LBUF(128+K)
0037      IBUF3(K)=MBUF(128+K)
0038      40  CONTINUE
0039      CALL WRITE (IDCB,IERR,IBUF0)
0040      CALL WRITE (IDCB,IERR,IBUF1)
0041      CALL WRITE (IDCB1,IERR,IBUF2)
0042      CALL WRITE (IDCB1,IERR,IBUF3)
0043      CALL CLOSE (IDCB,IERR)
0044      CALL CLOSE (IDCB1,IERR)
0045      STOP
0046      END

```

This program generates a sinusoid with phase distortion only.

```
LIST,$TEST1::45
$TEST1 T=00004 IS ON CR00045 USING 00005 BLKS R=0034
RWL3L1  FTM4
0002      PROGRAM TEST1
0003      INTEGER IDCB(272),NAM(3),IBUF0(256),IBUF1(256),LBUF(256)
0004      INTEGER ISIZE(2)
0005      ITYPE=2
0006      N=256
0007      ISIZE=2
0008      ISIZE(2)=128
0009  C      CALL CREAT(IDCB,IERR,NAM,ISIZE,ITYPE)
~010      DATA NAM/ 2HAD,2H00,2H4 /
0011      CALL CREAT(IDCB,IERR,NAM,ISIZE,ITYPE)
0012      DX1=360./FLOAT(N-1)
0013      DO 10 I=1,N
0014      X1=DX1*FLOAT(I-1)
0015      X=3.*SIN(X1*3.1415/180.)-42.
0016      X2=SIN(X*3.1415/180.)
0017      X3=COS(X*3.1415/180.)
0018      T=X2/X3
0019      T2=T*T
0020      X4=SQRT(1+T2)
0021      IF(T.GT.0) X4=-X4
0022      Q=T/X4
0023      IQ=128.*Q
0024      XI=SQRT(1.-Q*Q)
0025      II=128.*XI
0026      IF(II.GE.127) II=127
0027      IF(II.LE.-128) II=-128
0028      IF(IQ.GE.127) IQ=127
0029      IF(IQ.LE.-128) IQ=-128
0030      IF(II.LT.0) II=II+256
0031      IF(IQ.LT.0) IQ=IQ+256
0032      LBUF(I)=256*II+IQ
0033  10      CONTINUE
0034      DO 30 J=1,128
0035      IBUF0(J)=LBUF(J)
0036      IBUF1(J)=LBUF(J+128)
0037  30      CONTINUE
0038      CALL WRITEF(IDCB,IERR,IBUF0)
0039      CALL WRITEF(IDCB,IERR,IBUF1)
0040      CALL CLOSE(IDCB,IERR)
0041      STOP
```

Input for Case 1: 256 samples of sinusoid
listed from sequential
file, in decimal

30720	30976	31232	31488	31744	31992	32248	32496	32752	33008	33264	33520	33776	34032	34288	34544	34800	35056	35312	35568	35824	36080	36336	36592	36848	37104	37360	37616	37872	38128	38384	38640	38896	39152	39408	39664	39920	40176	40432	40688	40944	41200	41456	41712	41968	42224	42480	42736	42992	43248	43504	43760	44016	44272	44528	44784	45040	45296	45552	45808	46064	46320	46576	46832	47088	47344	47600	47856	48112	48368	48624	48880	49136	49392	49648	49904	50160	50416	50672	50928	51184	51440	51696	51952	52208	52464	52720	52976	53232	53488	53744	54000	54256	54512	54768	55024	55280	55536	55792	56048	56304	56560	56816	57072	57328	57584	57840	58096	58352	58608	58864	59120	59376	59632	59888	60144	60400	60656	60912	61168	61424	61680	61936	62192	62448	62704	62960	63216	63472	63728	63984	64240	64496	64752	65008	65264	65520	65776	66032	66288	66544	66800	67056	67312	67568	67824	68080	68336	68592	68848	69104	69360	69616	69872	70128	70384	70640	70896	71152	71408	71664	71920	72176	72432	72688	72944	73200	73456	73712	73968	74224	74480	74736	74992	75248	75504	75760	76016	76272	76528	76784	77040	77296	77552	77808	78064	78320	78576	78832	79088	79344	79600	79856	80112	80368	80624	80880	81136	81392	81648	81904	82160	82416	82672	82928	83184	83440	83696	83952	84208	84464	84720	84976	85232	85488	85744	86000	86256	86512	86768	87024	87280	87536	87792	88048	88304	88560	88816	89072	89328	89584	89840	90096	90352	90608	90864	91120	91376	91632	91888	92144	92400	92656	92912	93168	93424	93680	93936	94192	94448	94704	94960	95216	95472	95728	95984	96240	96496	96752	97008	97264	97520	97776	98032	98288	98544	98800	99056	99312	99568	99824	100080	100336	100592	100848	101104	101360	101616	101872	102128	102384	102640	102896	103152	103408	103664	103920	104176	104432	104688	104944	105200	105456	105712	105968	106224	106480	106736	106992	107248	107504	107760	108016	108272	108528	108784	109040	109296	109552	109808	110064	110320	110576	110832	111088	111344	111600	111856	112112	112368	112624	112880	113136	113392	113648	113904	114160	114416	114672	114928	115184	115440	115696	115952	116208	116464	116720	116976	117232	117488	117744	118000	118256	118512	118768	119024	119280	119536	119792	120048	120304	120560	120816	121072	121328	121584	121840	122096	122352	122608	122864	123120	123376	123632	123888	124144	124400	124656	124912	125168	125424	125680	125936	126192	126448	126704	126960	127216	127472	127728	127984	128240	128496	128752	129008	129264	129520	129776	130032	130288	130544	130800	131056	131312	131568	131824	
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Input for Case 2:

[illegible]

STOF

Input for Case 1: Octal Format

:LIST,AD000

AD000 T=00002 IS DN CR00002 USING 00002 BLKS R=0128

REC# 00001

074000	074400	074400	074400	074400	074400	074400	075000*
075000	075000	075000	075000	075000	075400	075400	075400*
075400	075400	075400	076000	076000	076000	076000	076000*
076000	076000	076400	076400	076400	076400	076400	076400*
076400	076400	077000	077000	077000	077000	077000	077000*
077000	077000	077000	077400	077400	077400	077400	077400*
077400	077400	077400	077400	077400	077400	077400	077400*
077400	077400	077400	077400	077400	077400	077400	077400*
077400	077400	077400	077400	077400	077400	077400	077400*
077400	077400	077400	077400	077400	077400	077400	077400*
077400	077400	077400	077400	077400	077400	077400	077400*
077000	077000	077000	077000	077000	077000	077000	076400*
076400	076400	076400	076400	076400	076400	076000	076000*
076000	076000	076000	076000	076000	075400	075400	075400*
075400	075400	075400	075000	075000	075000	075000	075000*
075000	074400	074400	074400	074400	074400	074400	074000*

REC# 00002

074000	074000	074000	074000	074000	073400	073400	073400*
073400	073400	073400	073000	073000	073000	073000	073000*
073000	072400	072400	072400	072400	072400	072400	072400*
072000	072000	072000	072000	072000	072000	072000	072000*
071400	071400	071400	071400	071400	071400	071400	071400*
071400	071400	071000	071000	071000	071000	071000	071000*
071000	071000	071000	071000	071000	071000	071000	071000*
071000	071000	071000	071000	071000	071000	071000	071000*
071000	071000	071000	071000	071000	071000	071000	071000*
071000	071000	071000	071000	071000	071000	071000	071000*
071000	071000	071000	071000	071000	071400	071400	071400*
071400	071400	071400	071400	071400	071400	071400	072000*
072000	072000	072000	072000	072000	072000	072000	072400*
072400	072400	072400	072400	072400	072400	073000	073000*
073000	073000	073000	073000	073000	073400	073400	073400*
073400	073400	073400	074000	074000	074000	074000	074000*

Input for Case 2: Octal Format

LIST,AD001

AD001 T=00002 IS ON CR00002 USING 00002 BLKS R=0128

REC# 00001

074000	074400	074400	074400	074400	075000	075000	075000◆
075000	075400	075400	075400	075400	076000	076000	076000◆
076000	076000	076400	076400	076400	076400	076400	076400◆
077000	077000	077000	077000	077000	077000	077000	077000◆
077000	077000	077400	077400	077400	077400	077400	077400◆
077400	077400	077400	077000	077000	077000	077000	077000◆
077000	077000	077000	077000	077000	077000	076400	076400◆
076400	076400	076400	076400	076400	076000	076000	076000◆
076000	076000	076000	075400	075400	075400	075400	075400◆
075000	075000	075000	075000	075000	075000	074400	074400◆
074400	074400	074400	074400	074400	074000	074000	074000◆
074000	074000	074000	074000	074000	074000	074000	074000◆
073400	073400	073400	073400	073400	073400	073400	073400◆
073400	073400	073400	073400	073400	073400	073400	073400◆
073400	073400	073400	073400	073400	074000	074000	074000◆
074000	074000	074000	074000	074000	074000	074000	074000◆

REC# 00002

074000	074000	074400	074400	074400	074400	074400	074400◆
074400	074400	074400	074400	074400	074400	074400	075000◆
075000	075000	075000	075000	075000	075000	075000	075000◆
075000	075000	075000	075000	075000	075000	075000	075000◆
074400	074400	074400	074400	074400	074400	074400	074400◆
074400	074400	074000	074000	074000	074000	074000	074000◆
074000	073400	073400	073400	073400	073400	073400	073000◆
073000	073000	073000	073000	073000	072400	072400	072400◆
072400	072400	072400	072000	072000	072000	072000	072000◆
072000	071400	071400	071400	071400	071400	071400	071400◆
071400	071400	071400	071400	071000	071000	071000	071000◆
071000	071000	071000	071000	071000	071000	071000	071400◆
071400	071400	071400	071400	071400	071400	071400	071400◆
071400	072000	072000	072000	072000	072000	072000	072400◆
072400	072400	072400	072400	073000	073000	073000	073000◆
073400	073400	073400	073400	074000	074000	074000	074000◆

Input for Case 3: Octal Format

LIST AD004

AD004 T=00002 IS ON CR00002 USING 00002 BLKS R=0128

REC# 00001

057653	057653	057653	057653	057653	057653	057654	057654♦
057654	060254	060254	060254	060254	060254	060255	060255♦
060255	060255	060655	060655	060655	060655	060655	060656♦
060656	060656	060656	060656	060656	061256	061256	061256♦
061256	061257	061257	061257	061257	061257	061257	061257♦
061257	061257	061257	061257	061257	061657	061657	061660♦
061660	061660	061660	061660	061660	061660	061660	061660♦
061660	061660	061660	061660	061660	061660	061660	061660♦
061660	061660	061660	061660	061660	061660	061660	061660♦
061660	061660	061660	061660	061660	061660	061660	061660♦
061660	061657	061657	061657	061257	061257	061257	061257♦
061257	061257	061257	061257	061257	061257	061257	061256♦
061256	061256	061256	060656	060656	060656	060656	060656♦
060656	060656	060655	060655	060655	060655	060255	060255♦

060255	060255	060254	060254	060254	060254	060254	060254♦
BP CODE ERR							
057654	057654	057654	057653	057653	057653	057653	057653♦

REC# 00002

057653	057253	057253	057252	057252	057252	057252	057252♦
057252	057252	056652	056651	056651	056651	056651	056651♦
056651	056651	056651	056651	056250	056250	056250	056250♦
056250	056250	056250	056250	056250	056250	056250	055647♦

055647	055647	055647	055647	055647	055647	055647	055647♦
BP CODE ERR							
055647	055647	055647	055647	055647	055246	055246	055246♦
055246	055246	055246	055246	055246	055246	055246	055246♦
055246	055246	055246	055246	055246	055246	055246	055246♦
055246	055246	055246	055246	055246	055246	055246	055246♦
055246	055246	055246	055246	055246	055246	055246	055246♦
055246	055246	055646	055647	055647	055647	055647	055647♦
055647	055647	055647	055647	055647	055647	055647	055647♦
055647	056250	056250	056250	056250	056250	056250	056250♦
056250	056250	056250	056251	056651	056651	056651	056651♦
056651	056651	056651	056651	056652	057252	057252	057252♦
057252	057252	057252	057252	057252	057253	057653	057653♦

Input for Case 3:
Decimal Format

24491	24491	24491	24491	24491	24491	24492	24492
24492	24748	24748	24748	24748	24748	24749	24749
24749	24749	25005	25005	25005	25005	25005	25006
25006	25006	25006	25006	25006	25262	25262	25262
25262	25263	25263	25263	25263	25263	25263	25263
25263	25263	25263	25263	25263	25519	25519	25520
25520	25520	25520	25520	25520	25520	25520	25520
25520	25520	25520	25520	25520	25520	25520	25520
25520	25520	25520	25520	25520	25520	25520	25520
25520	25519	25519	25519	25523	25263	25263	25263
25263	25263	25263	25263	25263	25263	25263	25262
25262	25262	25262	25006	25006	25006	25006	25006
25006	25006	25005	25005	25005	25005	24749	24749
24749	24749	24748	24748	24748	24748	24748	24748
24492	24492	24492	24491	24491	24491	24491	24491
24491	24234	24234	24234	24234	24234	24234	24234
24234	24234	23977	23977	23977	23977	23977	23977
23977	23977	23977	23977	23720	23720	23720	23720
23720	23720	23720	23720	23720	23720	23720	23463
23463	23463	23463	23463	23463	23463	23463	23463
23463	23463	23463	23463	23206	23206	23206	23206
23206	23206	23206	23206	23206	23206	23206	23206
23206	23206	23206	23206	23206	23206	23206	23206
23206	23206	23206	23206	23206	23206	23206	23206
23206	23206	23462	23463	23463	23463	23463	23463
23463	23463	23463	23463	23463	23463	23463	23463
23463	23720	23720	23720	23720	23720	23720	23720
23720	23720	23720	23721	23977	23977	23977	23977
23977	23977	23977	23977	23978	24234	24234	24234
24234	24234	24234	24234	24234	24235	24491	24491 STOP



*MISSION
of
Rome Air Development Center*

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C³I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

END

DATE
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10-81

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